**Innovation strategy in new transportation systems: the case of Crossrail**

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**ABSTRACT**

This article examines how innovation can be strategically incorporated into transportation systems. Large transportation systems generally have a poor record in systematically integrating innovation in their development, construction and operation. Our research setting is Crossrail, a major new railway traversing London, where the creation and implementation of an innovation strategy formalized and systemized its approach to innovation. Based on in-depth, semi-structured interviews with project leaders and participant observation, the paper critically analyses the formulation, implementation and performance of Crossrail's innovation strategy. Crossrail's management explicitly uses an 'open innovation' strategy that incentivizes partners, contractors, and clients to innovate in the project. Its strategy guides decisions and priorities on innovation and the types and levels of innovation that best match project aims. The paper holds lessons for those developing, operating and studying large transportation systems both now and into the future.

## 1. INTRODUCTION

### 1.1 The nature and importance of innovation strategy

In this journal, 30 years ago, Professor Jerry Ward presciently outlined some of the possibilities, trends and processes in transportation innovation (Ward, 1984). Transportation technology for Ward was an integral part of the fabric of technological progress in society, and he highlighted a wide range of possible innovations in the field. Ward was also very conscious of the constraints on innovation. It was something that was often feared and resisted, he argued, and the interactions within and between transportation systems and other infrastructure systems required a demanding level of compatible and synergistic evolution that added huge complexity to the innovation process. He also wryly observed that: "Risk and failure are intrinsic to the innovation process, and the tolerance for both in publicly funded projects is low" (Ward, 1984:287).

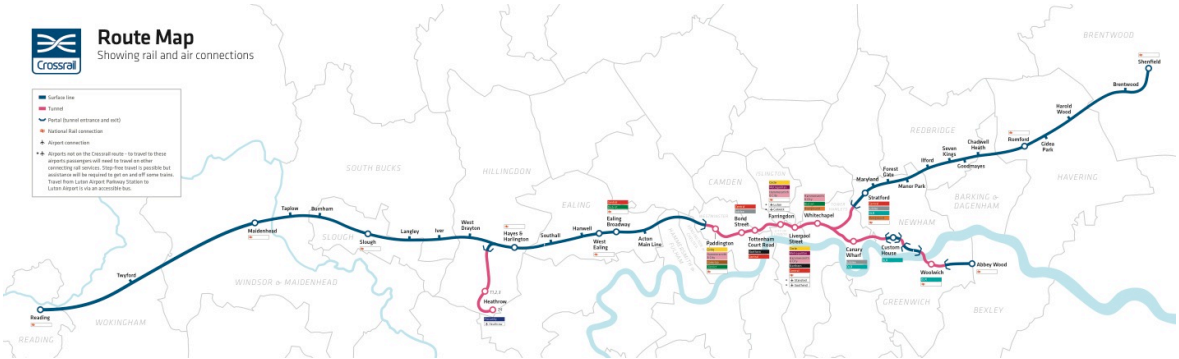
Ward's views on the importance and challenges of innovation in transportation remain germane today. We can divide the activities of organizations involved in transportation systems into two categories: projects and operations (Shenhar and Dvir, 2007). Projects involve the unique, one-time activities to design, construct new systems or renovate and maintain established ones. Operations involve the repetitive, continuing activities involved in providing transportation services to end users. While project and operations are often undertaken in distinct and temporally separated stages, they are interwoven activities, forming a project-operation system innovation

cycle (Geyer and Davies, 2000). Innovation in design and construction during the project stage must deal with changing current operational requirements and anticipate future conditions many years after project completion. By examining the way innovation, both planned and emergent, can be built into the design, construction and future operational requirements of a major transportation system, this paper shows how a strategic management approach can help deliver today's possibilities, trends and processes in transportation innovation.

Innovation is a novel product, process, service or means of organization that changes the prevailing order (Freeman and Soete, 1997; Van de Ven, 1999). It ranges from incremental improvements through to radically new ideas that transform the practices and structures of existing institutions. In most industries it is widely understood that enhancements in performance depend on innovation, and that effective innovation requires a strategic approach. Yet the development and use of innovation strategy is notoriously difficult, and few companies have consistently managed to develop technological innovation in a strategic manner (Dodgson et al, 2008).

This paper addresses the development and deployment of an innovation strategy in Crossrail, a new 118km metro railway running across London (see Figure 1). It describes key aspects of generic innovation strategies found in a wide range of industries, and then examines these aspects in Crossrail. A feature of innovation strategy is the way it systemizes decision-making and efforts to improve innovation within and across organizations, involving many of their different parts and functions. An innovation strategy helps organizations make choices about the types and levels of innovation that best match corporate aims. It guides decisions and priorities on how resources are to be used to deliver value to clients and customers, and by building organizations' capacities to adapt, helps them to react to unforeseen events.

**Figure 1. Crossrail Route**




In practice, innovation strategies involve statements that are expressions of leadership on the role of innovation in meeting corporate objectives. These statements articulate the organization's innovation ambitions and long-term objectives. Innovation strategies also outline the plans and processes to be used for developing and mobilizing resources to support innovation. A fundamental tenet of innovation strategy is that innovation is a collaborative process, both internally and externally. Internally, ideas for innovation and their application require the engagement of a variety of people with diverse expertise, working together.

Externally, innovation requires inputs from a variety of contributors ranging from research institutes to customers and suppliers.[1]

This article addresses two particularly important aspects of innovation strategy: how it relates to the *capabilities* - bundles of skills – needed to find, choose and apply innovative ideas; and efforts to encourage *open innovation* (defined subsequently in this paper) within the supply chain, and with research partners and clients. It analyzes how Crossrail has formalized and systematized an approach to innovation that, it is argued, contrast with the short-term, piecemeal and opportunistic forms of working commonly found in such projects (Armitt, 2012).

### 1.2 The challenges of innovation strategy in large transportation projects

The risk and uncertainty of large infrastructural projects, such as railways, airports, and dams, lead to the avoidance of innovation (Van Marrewijk et al, 2008). There is great reluctance in such projects to introduce novel ideas and innovative approaches on the part of clients and contractors, who often seek to minimize risks by relying on tried-and-tested techniques, established routines, and proven technologies (Miller and Lessard, 2000; Flyvbjerg, Bruzelius, & Rothengatter, 2003; Gil & Beckman, 2009; Flyvbjerg, Garbuio, & Lovall, 2009; Merrow, 2011). Innovation is deterred by preference for lowest-price bids, and management practices that stick rigidly to original plans, even when circumstances change. This view is summed up by Andy Mitchell, then Program Director at Crossrail, in an interview with *New Civil Engineer*: "when it comes to innovative ideas…on major projects the natural state of mind is to control risk by using the tried and tested" (Oliver, 2012b, p. 11). In a review of the literature, Davies et al (forthcoming) found no examples of organizations—sponsors, clients, prime contractors or joint-venture delivery partners—creating deliberate strategies and organizational processes designed to generate and implement innovation within a major project.

This situation, however, may be changing. Over the past decade, the UK has seen a stronger emphasis on innovation in government sponsored reports (Latham, 1994; Egan, 1998; Wolstenholme, 2009; Armitt, 2012) and a number of examples of experimentation, learning, and innovation in project delivery models, such as Heathrow Terminal 5 and the London Olympics (Davies, Gann & Douglas, 2009; Brady & Davies, 2014). These new models include Crossrail, which is currently Europe's largest infrastructure engineering project. Innovation has been a concern for the project since its approval to proceed in 2008. In an interview that year with *New Civil Engineer*, Doug Oakervee, Crossrail Executive Chairman, outlined the project's overall strategic approach to innovation. He announced that: "we will always be looking for innovation and ways of doing things more economically and they will be prime motivators in all of the incentive schemes" and that "Innovation is the thing we have to work with—and that will be a partnership between us and the delivery partner and designers to deliver in the most efficient way to produce the best economies" (Oliver, 2008a, p. 6).

[1] For a comprehensive review of the nature and contribution of innovation management see Dodgson, Gann and Phillips (2014).

In September 2012 Crossrail published an 18-page document: *Crossrail Innovation Strategy: Moving London Forward*. This strategy document outlines Crossrail's vision for innovation and emphasizes how crucial it is to equip people in the organization and supply chain with the knowledge, processes, and incentives necessary to help them search for novel ideas, collaborate, and generate innovation. In the preamble to the strategy document, Crossrail's CEO, Andrew Wolstenholme writes:

"Innovation is… a subject I am passionate about... I am confident that we can …develop a strategy on Crossrail where people are encouraged to think differently. If we get it right we will see a level of innovation that is unprecedented on a major programme like Crossrail".

Crossrail's strategic management of innovation has seen new innovations generated, the transfer of existing innovations across its various subprojects, and the engagement of clients in decisions about innovation. This elevation of the role of innovation has played an important role in helping the organization adapt to technological change.[2] The objective and focus of the strategy is the delivery of a world-class railway. Innovation is sought for the way it can contribute to the operation and use of an efficient and effective transport system for its clients and users. By building innovative capacity into the project, the system can more robustly deal with subsequent, occasionally unforeseen, change. The case of Crossrail helps illuminate the links between the design, construction and use of a major transportation system, and its strategic approach to innovation helps address Ward's (1984) conundrum of how to introduce its multiple benefits in the face of its many challenges.

## 2. METHODS

### 2.1 The case

Crossrail is a £14.8 billion project building a new railway in South East England from Reading and Heathrow Airport through central London to Shenfield and Abbey Wood. The project had 14,000 people working on it at its peak, and has involved building 37 stations and 42 kilometres of tunnel. Crossrail trains will be just over 200m long, made up of nine walk-through carriages, with the capacity to carry 1,500 passengers. Station platforms are designed to accommodate 240m long trains to provide the capacity required to adapt to forecasted increases in demand. The signaling system will control the movement of 24 trains an hour through the central section with the possibility of increasing to 32 trains an hour if extra capacity is required. The new trains will be progressively introduced to sections of the existing rail network in advance of full Crossrail services commencing in December 2018. It is predicted that,

[2] When visiting Crossrail sites, for example, it is remarkable to observe the number of iPads in use. These were not invented when Crossrail began and there are many opportunities for using them during the construction process. For example, field engineers can use an iPad to make and upload media-rich observation reports in real-time, instead of taking these notes on paper and then going back to the office and then typing up the report and sending it off. It is possible to stand in a tunnel under construction, point an iPad and 'see' virtually where the platform is and watch a train arriving. However, iPads (like mobile phones) were originally banned on Crossrail sites due to concerns about health and safety. Crossrail's formal innovation process played an important role in identifying opportunities to use iPads and then organizing technology trials to produce safe working guidelines to enable Crossrail's sites to adapt to their use.

upon completion, Crossrail will increase London's rail-based capacity by 10% and be used by approximately 200 million passengers a year. The new railway will bring an additional 1.5 million people within a 45-minute commute from London's major commercial districts.

Crossrail is a large and complex programme of interrelated projects that have to be integrated to create the new railway system. The project itself has to be integrated with the existing overground and underground rail network systems.[3] Crossrail Limited (henceforth Crossrail) was established in 2008 as a special purpose delivery organization responsible for the development and delivery of the system, including all its component projects. Crossrail is the overall program manager and systems integrator for the railway. It is accountable to the joint project sponsors: the Department for Transport (DfT) and Transport for London (TfL).

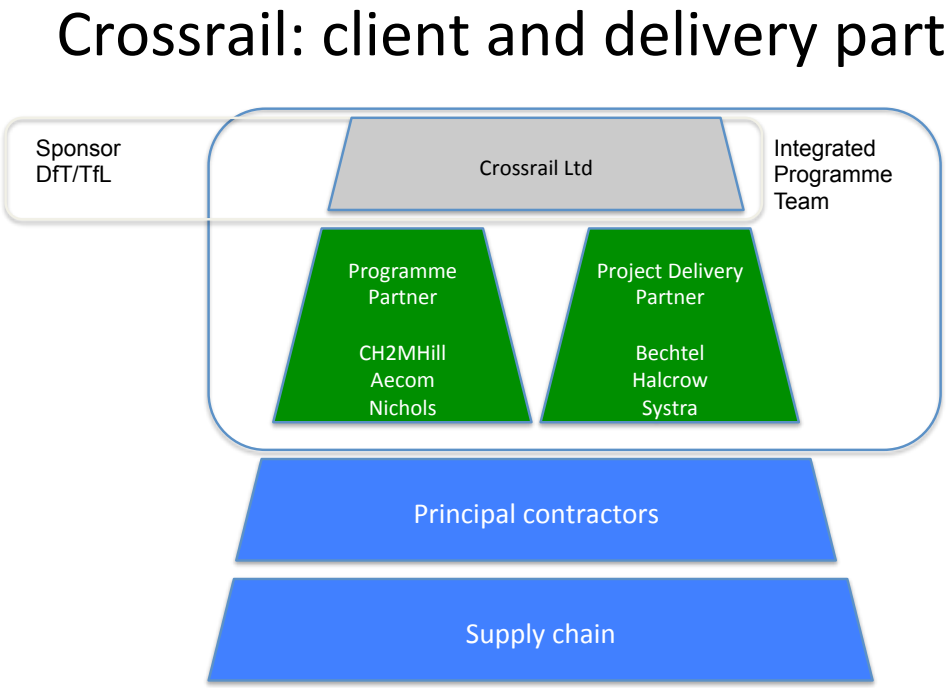
In 2017 and 2018, Crossrail will begin the transition from a delivery organization into an operating railway. Crossrail is responsible for the handover of the assets and working closely with Crossrail infrastructure managers and operators throughout the project life cycle from conceptual design, through construction, integration, testing, trial running, handover, and operation of rail services. Crossrail is part of a complex ecosystem of independent but interdependent organizations responsible for operating different aspects of London's transportation network:

- Rail for London (RfL) is the infrastructure manager, and future operator of several Crossrail stations.
- MTR (the Hong Kong metro operator) won a contract for eight years with an option to extend to 10 years to run the Crossrail train service as the Crossrail Train Operating Company (CTOC).
- Network Rail, the owner and operator of most of Britain's railway infrastructure, is undertaking a major upgrade over its overground network to prepare for the cross-London service and interfaces with sections in central London.
- London Underground Limited (LUL) owns and operates London's public rapid transit system and works with CRL to integrate Crossrail works with its own capital projects.
- Transport for London (TfL), is responsible for most components of London's transportation system including LUL (a wholly owned subsidiary of TfL).

The structure of the project is shown in Figure 2.

[3] As an example of the degree of connectedness and some of the significant engineering challenges faced, on one occasion a Crossrail tunnel boring machine operated at the middle of the day separated by less than one metre from the fully operating Northern Line underground.

**Figure 2: Crossrail partners**




Source: Developed by authors based on presentation by Andy Mitchell, former Crossrail Programme Director. Note: Halcrow was acquired by CH2MHill in 2011.

## 2.2 Research methods

Our study was conducted using the classic case study method (Yin, 2003). Given the rarity of studies in the field, the Crossrail case was purposively selected because it provided the access required to collect data on a pioneering effort to develop an innovation strategy in a major transportation project.

Data was collected using a combination of semi-structured interviews and participant observation[4] (Miles and Huberman, 1994). The semi-structured interviews (n=16) were conducted in mid-2012 with senior managers involved in developing and implementing Crossrail's innovation strategy. Each interview focused on understanding the strategic logic driving the introduction and implementation of the innovation strategy.

The interviews provided excellent contextual data, but biases related to recall and social desirability limit the utility of this data for understanding strategic decision-making (Golden, 1992; Langley et al 1995). Our main source of data for studying Crossrail's innovation strategy was, therefore, based on participant observation.

[4] Observational data was recorded through fieldnotes, whereas the interviews were digitally recorded.

Participant observation, while a commonly used technique in anthropology, sociology and management studies (Ragin, Nagel and White, 2004), is less well known beyond these areas and deserves special mention. In this technique the researcher "adopts the simultaneous dual role of active participator in the organization's activities and observer of those activities" (Gioia and Chittipeddi, 1991: 435).

Participation provides the researcher with deep insight into the process by which people make sense of strategic action and, by legitimising their presence, opens the door to events and discussions that would normally be off-limits to outsiders (Spradley, 1980). Two members of the research team acted as participants from early 2012-2014, providing an academic perspective on innovation when asked. The sort of knowledge Crossrail staff were interested in was that which could be found in innovation scholarship, such as a description of different types of innovation (e.g. process vs. product) or the principles behind an open innovation strategy. This advice continued as the innovation strategy was developed.

We used this access to gather observational data on real-time strategic decision-making, participating in weekly meetings, site visits and workshops related to the management of innovation over a 2.5 year period, totaling in excess of 300 days of participation. Fieldnotes were made and archival material (e.g. data on specific innovations) collected on a wide variety of topics related to innovation, addressing questions ranging from "*what should the organizational structure underpinning the innovation process look like*?", "*what's our strategy*?" through to "*where will funding come from*?".

Participation and immersion do, however, carry the well-known risk of "going native", a state in which the researcher comes to completely identify with and adopt the perspective of those under study, and thus lose the objective distance required to conduct a dispassionate analysis. We follow the traditional approach for managing this tension, with some members of the research team adopting the role of "insiders", who participated in the strategy development process[4], and others adopting the role of non-participant "outsiders" who help ensure a detached analysis of data (Langley and Abdallah, 2011).

This combination of techniques enabled us to gain detailed insight into the reasons motivating Crossrail's innovation strategy as well as the data describing its implementation.

## 3. THEORY

There is an extensive literature on innovation strategy (for a recent review, see McGrath and Kim, 2014), and our analysis is embedded within two of its core strands: 'capabilities' and 'open innovation', both of which are of considerable contemporary interest in the management literature. A central stream of corporate strategy research refers to the 'dynamic capabilities' organizations need to build competitive advantage (Teece et al, 1997). A number of these capabilities assist the creation and implementation of innovation strategy (Helfat et al. 2007), while their development and use is a core feature of it (Dodgson et al, 2008). These capabilities are described below along with some of their practical implications.

*Searching*: seeking and assessing market and technology opportunities. Forward-thinking organizations welcome any information, guidance, or advice on likely future developments in their areas of science, technology, and engineering.

*Selecting*: choosing amongst future options based on the results of search activities, an evaluation of available resources, and the probability of value creation. The selection of new technologies entails choosing which technologies are core to the organization or project, and where it needs a proprietary position. Choices need to be made on which technologies to concentrate on developing internally, and which to access externally, through purchase or collaboration.

*Configuring*: ensuring the coordination and integration of innovation efforts. Configuring innovation entails acquiring new technological resources, as well as coordinating and integrating all the different activities involved in the innovation process.

*Deploying*: delivering internally generated and acquired innovations on time and to budget, and protecting and delivering value from innovation. The effective deployment and implementation of innovations is much easier when there are established processes for agreeing on the importance of particular technologies and their relevance.

*Learning*: improving the performance of innovation processes through experimentation and experience. Learning can be described as the way organizations build, supplement, and organize knowledge, and adapt and develop organizational efficiency through improving the use of that knowledge. The need to learn is commonly explained by a requirement for adaptation and improved efficiency in times of change. Organizations learn to do existing things better, learn to do new things, and learn how to learn more effectively (Argyris and Schon, 1978). Innovation strategy is especially engaged with the latter two forms of learning, which do not result simply from repetition of an activity, or 'learning by doing', and are actively sought and purposive in nature.

One of the most important recent theoretical developments in the field of innovation strategy is the concept of 'open innovation' (Chesbrough, 2006). Applied particularly to the large R&D undertaking firm, research in open innovation is motivated by an interest in how to strategically shape the porousness of organizational boundaries to increase the trading – the buying and selling – of the knowledge and intellectual property that supports innovation (West et al, 2014). It has long been known that few, if any, organizations innovate by themselves, yet the currency and enthusiasm for open innovation amongst academics has perhaps not been matched by the ease with which organizations apply it. Nonetheless, with careful delineation of its nature and application, the concept helpfully captures some key elements of innovation strategy. Helpful in this regard is the distinction between two different forms of inbound innovation — acquiring and sourcing — and two forms of outbound—selling and revealing (Dahlander and Gann, 2010). Acquiring and selling are pecuniary in nature, while sourcing and revealing are non-pecuniary.

In Dahlander and Gann's (2010) terms, acquiring relates to buying inputs to the innovation process in the marketplace. The challenge is viewed as one of combining the acquisitions of knowledge with internal expertise to search for and evaluate potential inputs. Sourcing stems from how organizations scan and use the external environment as input to the innovation process. Scholars who use this lens focus on how firms explore their environment as a complement to their internal knowledge production, which might in fact be limiting them in their quest for new ideas to use in innovation. These broadly equate with the dynamic capabilities of searching and selecting, and are key components of open innovation strategies that aim to deliver a level of coherence and focus that did not exist previously.

Establishing and building the external orientation of organizations in their search for innovation does not occur easily or automatically. There is long-standing evidence documenting organizational tendencies towards introspection and parochialism (March, 1991; Allen, 1982), a tendency also noted in transportation projects by Ward (1984). To be successful at open innovation organizations need to foster a culture of openness and recognition that the best ideas often emanate from the outside, and this involves incentive structures encouraging employees to be externally orientated (Alexy and Dahlander, 2014).

Large infrastructure projects, such as Crossrail, are usually built through the assembly of a temporary coalition of organizations, commonly relying on the configuration of external skills and technologies. As such, this transportation project provides a valuable research site in which to explore the nature and form of open innovation in an organization different to the large R&D undertaking firm. It also provides an opportunity for transportation researchers to analyse the extent to which this external orientation can be valuably guided by an overarching, coherent strategy.

## 4. RESULTS/FINDINGS

### 4.1 Background to Crossrail's Innovation Strategy

The motivation to develop an innovation strategy has to be considered in the context of a wider concern to improve innovation performance in the construction of UK infrastructure in general and the championing of innovation by Crossrail's CEO.

Over the last 20 years there has been a series of government reports identifying performance problems within the UK construction industry and calling for a wide range of improvements (e.g. Egan, 1998; Armitt, 2012), especially an increased focus on innovation. There has been some change as a result. For example, in response to Egan (1998), the industry organized a group called "Movement for Innovation" (Mi4) to pursue innovative demonstrator projects[5]. Greater innovation has been actively sought in major projects, such as Heathrow Airport Terminal 5 (Davies, Gann and Douglas, 2009).

Andrew Wolstenholme had been programme director on Heathrow Terminal 5, and looking back on it he realized that, while there was much innovation generated within

[5] In 2003 Mi4 was combined with related initiatives to create the industry association called "Constructing Excellence".

the project, there was more that could be done to make it a more strategic consideration. In 2009 he Chaired a government and industry review of the state of the UK construction industry (Wolstenholme, 2009), arguing the need for considerable improvements. Immediately prior to joining Crossrail in September 2011, Wolstenholme was Director for Innovation and Strategic Capability at Balfour Beatty, a major construction company, where his views on innovation strategy developed further.

In an interview in *New Civil Engineer,* Wolstenholme argued that there was a strategic opportunity to use the Crossrail project "to lever in new ideas, techniques and processes that will genuinely change the industry in future" (Oliver, 2012a, p. 8). The approach adopted by Crossrail was driven by three major concerns. First, ensuring that best practices in innovation were being adopted from wherever they were to be found, including other industries. Second, capturing extra value by ensuring that lessons learned about innovation in one component project were transferred to other projects, including between different contractors. Third, capturing lessons about innovation to be applied in subsequent transportation projects.

The challenge to innovate and to do so in a systematic and value creating manner is particularly acute because of the pressure to deliver the project on time and on budget, and initially there was no formal budget allocated to innovation. This challenge also has to be considered in the context of the highly complex structure of the Crossrail programme with its numerous intertwined and often competing organizations, and the additional complication arising from catering to numerous clients, one of which, the CTOC, MTR, was not appointed until 2014.

### 4.2 Crossrail's innovation strategy

The stated purpose of the Crossrail Innovation Strategy (see Table 1) is to achieve the project's overall goals and vision of creating a world-class railway while meeting targets on time, cost, quality and safety.[6] The Strategy document clearly defines innovation and its various levels.[7] It took Crossrail approximately six months to develop its innovation strategy, three months to pilot it at selected sites, and another three months to revise and then roll it out across the programme. The document appeared halfway through the Crossrail project, with the delay reflecting the challenge of coordinating so many varied and competing interests. Indeed, one of the purposes of the strategy was to unite the diverse contributions around a shared agenda.

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**Table 1**. Illustrative statements from Crossrail innovation strategy.

"Our vision for an innovation strategy at Crossrail include(s) processes that:
- Generate, develop, codify and formalize innovation in Crossrail's design, construction and handover to operations

[6] Some of these and further details on some specifics of Crossrail's innovation strategy can be found in Davies et al (forthcoming).

[7] The word 'innovation' can be used loosely, and clarifying its specific nature and levels is critical to its effective understanding and communication (Dodgson, Gann and Phillips, 2014).

- Benchmark and measure innovative improvements
- Capture and transfer lessons to future projects"

"Crossrail's strategy is to deliver a world-class railway where innovation goals are clearly targeted as everyone's responsibility, and collaboration across the programme's boundaries is used to create a legacy that moves London forward".

"Raising the performance bar to the next level requires strategic efforts to promote innovation and learning from one project to the next. Innovation is surrounded by risk and uncertainty. The question is: How can we exploit the innovation capabilities of the Crossrail supply chain to create a high performance railway without sacrificing affordability, safety or the environment? This document outlines Crossrail's strategy for meeting this challenge."

"Crossrail is learning from organisations…that have world-class innovation programmes. These organisations – such as Procter and Gamble, Rolls Royce, Siemens and IBM – have created programmes to support rapid and systematic innovation. They are now establishing 'open innovation models' to search for the best external ideas, discoveries and technologies and connect these with internal capabilities".

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The strategy document identifies the organizational processes designed to drive the search, selection, configuration and deployment of new innovation ideas. The core principle was the creation of a pathway whereby people from across the supply chain could channel their ideas for innovation, gain the resources required to implement them, and then share successes across organizational boundaries. This process was supported by a small and dedicated "innovation team" that was given the job of helping identify, evaluate and develop ideas, project manage a portfolio of invested projects, and broker successful innovations across the project. An online innovation portal – "innovate18"[8] - has been developed to provide a mechanism on which to submit ideas (see Figure 3 for a description of one project) and then an Innovation Management System is used to manage, track and report on their progress and to communicate and share innovations across the Crossrail ecosystem via the website. The group of contributors to the innovation portal has in excess of 900 active members, and it had a library of over 270 innovations published online as of November 2014.

[8] www.innovate18.co.uk

**Figure 3: Example innovation project**


The strategic management of innovation requires coordination across multiple organizational levels. We observed how strategic direction and governance are provided at Crossrail by a body called the Crossrail Innovation Forum[9] (CIF). The CIF meets bi-annually and reviews the portfolio of innovations currently under development and evaluates new opportunities identified for investment. While membership of the CIF, which includes all the major partners in the project, has been relatively stable, pressure on non-contributors can be exerted with the threat of exclusion. Day-to-day implementation and management of the innovation program, including the online tools and portfolio of innovation projects, is devolved to the innovation team. The team consists of the:

- Director of Innovation, who has oversight of the innovation programme and liaises with senior staff at Crossrail, contractors and clients.
- Innovation Programme Manager, who manages the programme to ensure the objectives of the Crossrail Innovation Strategy are delivered.
- Innovation Coordinators, who are responsible for facilitating the development of innovations within specific organizational units (e.g. specific sites; functional sections) and brokering existing innovations across the project (e.g. the use of Quick Response codes for tracking temporary assets). A core part of their role is helping innovators navigate the complex organizational landscape that knits together a major project like Crossrail. They are responsible for

[9] Factual information on policies and procedures was drawn from archival data (Crossrail's Innovation Management Plan; Crossrail presentations) and our fieldnotes based on meetings.

facilitating innovation evaluation by the relevant technical specialists and, if necessary, mobilize task groups to support the development of an innovation idea. Their role includes monitoring progress and providing regular status updates. There has been some labour turnover in this role, which to some extent reflects its different needs as the project progresses.

- Innovation Reporting Assistant, who is responsible for reporting the status and health of the innovation programme including communications and publications. The role includes the collection and presentation of monthly innovation programme reports, as well as data on the implementation of each innovation project underway.
- Innovation Champions, who are located in projects and functional departments with the specialized knowledge needed to help the innovation team evaluate and select good ideas.

#### 4.2.1 The Innovation Process

Our fieldwork identified five stages in the Crossrail innovation process. The innovation process began when one or more members of the Crossrail project supply chain submit a new idea via an online portal (Stage 1: Submission). An innovation coordinator then contacted the person who submitted the idea and works with technical experts and innovation champions to evaluate its potential. Ideas judged as likely to provide value to Crossrail were developed, gaining the relevant sponsorship and commitment from the necessary parties (Stage 2: Discovery). Ideas were then evaluated every six months by an innovation working group[10] comprised of technical experts, representatives of the contractors, and representatives of the Innovation Programme team, which selects those ideas worthy of consideration for investment to develop selected ideas into useful products, processes, and technologies (Stage 3: Competition). Their recommendations were then ratified by the CIF, which is ultimately responsible for deciding which innovation opportunities will be pursued (Stage 4: Evaluation and Selection). Once selection has occurred, a project team was assembled to manage the implementation of each innovation (Stage 5: Implementation).

By October 2014, the innovation program had completed three rounds of evaluation, received over 700 innovation ideas and provided resources to support the development of 102 innovations. Over £350,000 has been allocated to the support of these innovations, with half of the funding derived from 11 partners in the supply chain and the remainder from Crossrail. Our study shows how the portfolio of innovation ranged widely, from the incremental through the more radical (see Table 2).

**Table 2: Examples of innovation portfolio**

| Level of Innovation | Illustrative Examples |
|---|---|
| Incremental | 1. High definition drone-mounted camera for site inspections: Produce a video stream that can be |

[10] We attended this working group as part of our participant observation.

| | |
|---|---|
| | used to carry out site inspections. The stream would make expensive aerial photographs redundant, reduce the need for field engineers to travel across sites to carry out inspections, and make it easier to access restricted areas (e.g. hazardous works; mass movement of plant). Transport for London has successfully trialled drones for carrying out inspections and monitoring site security.<br>Status: trial to develop procedures is being scoped.<br><br>2. Hydrophobic coating for concrete hopper: The application of a hydrophobic coating to the surface of concrete hoppers. This coating prevents concrete adhering to the hopper and speeds up concrete flow. Cleaning and maintenance costs are significantly reduced, and the risk profile of concreting is substantially reduced (e.g. lower risk of clogging).<br>Status: successfully implemented. |
| Intermediate | 1. Liftpro App: Lifting operations are a central part of the construction process (e.g. using an overhead crane to lift steel). These are high-risk activities and detailed planning is required to ensure they are conducted efficiently and effectively. Creating a lift plan is currently a time intensive task and requires a lot of traditional paper and pencil work. The Liftpro App is designed to bring this operation into the digital age. It stores information on common lifting machines used in the UK and then applies the standard calculations required to produce a lift plan. The App is designed to enable a plan to be produced in minutes instead of hours.<br>Status: under development.<br><br>2. Tactical Messages on Safety Gloves: Print tactical safety messages on the back of gloves. For instance, if a site is having problems with finger trapping injuries, a targeted safety message related to hand safety was developed to reinforce the site's safety message ("Don't give you finger to safety").<br>Status: Successfully trialed. |

| | |
|---|---|
| Radical | 1. Heat extraction from grout shafts: Tens of thousands of metres of grout shafts were developed to help stabilize the ground and prevent subsidence during the excavation process (following the "Tube a Machenette" method). They were originally going to be backfilled with concrete. However, it is possible that these grout shafts could be paired with a ground-sourced heat pump to produce geothermal energy. This energy could then be used to heat and cool Crossrail Stations and the over site developments that are being constructed above them.<br>Status: Under investigation<br><br>2. Real time micro-positioning system: This innovation uses Bluetooth beacons to generate high precision location data for mobile devices on construction sites. Existing technologies, such as GPS and WiFi triangulation, are not accurate enough nor work underground. The three main areas of application are: a) use location data to lock/unlock device functionality according to the safe operating conditions in a given area. This would make mobile devices safer to use and reduce resistance to having them on site. b) use location data to actively push relevant data (e.g. engineering drawings) to users rather than having them search through thousands of documents. c) make augmented reality applications easier to use (e.g. use a tablet to visualise construction sequences associated with a given space). The difficulty of getting accurate location data is currently constraining the use of augmented reality.<br>Status: field trials. |

### 4.3 Open innovation

Crossrail's open innovation approach applied to its supply chain, research partners and clients.

4.3.1 Supply chain

The desire to encourage suppliers to contribute innovations existed from the start of the project, before the creation of the Crossrail innovation strategy. For example, Crossrail created a procurement approach called "Optimised Contractor Involvement" (OCI) where each individual contractor, joint venture, and supplier can bring new ideas and practices to the project, whilst sharing the risk and reward. OCI was established to reduce the risks of projects, whilst exploiting innovative opportunities to improve performance. OCI incentivized contractors to invest in generating innovation on the project by guaranteeing that value created through innovation would be shared between the client and the contractor. Under OCI, the contractor is brought in after the target price has been established but early enough to have some input into the design and value engineering. To avoid encouraging suppliers to submit lowest-cost bids, Crossrail put increasing emphasis on the technical element to help select the best solution. Each of the contracts is awarded based on the technical ability of the joint ventures rather than on price. This process has been integrated into the innovation strategy, which connects it with other contributors to innovation in Crossrail and provides strategic oversight.

#### 4.3.2 Research Partners

In addition to collaborating on innovation with its contractors, Crossrail was also strategic about engaging with external organizations capable of carrying out applied research. Collaborating with external researchers is not unusual in large transportation projects. Crossrail's departure from normal practice lay in the way the creation of an innovation strategy provided the strategic logic and organizational architecture required to manage otherwise disparate initiatives as part of a related portfolio of innovation projects associated with a broader agenda. For example, the CIF identified concrete as a priority area for innovation. Subsequently, research was initiated with the University of Wolverhampton and Imperial College London on transforming London clay into an aggregate that could be used in concrete; by Cambridge University and Warwick University on using fibre optics to measure construction deformation; and by the UK National Physical Laboratory to use digital photography to monitor the application of sprayed concrete lining. These initiatives originated in different parts of the Crossrail organization but our research showed how they could now be managed and monitored as part of a broader initiative.

#### 4.3.3 Clients

A feature of an open innovation strategy is the involvement and engagement of clients and customers. Planning for the future 'digital railway' – with integrated common data and systems - is an example of this type of collaboration, with its operational and customer focus. Some of the components of the digital railway, and the way Crossrail is working with clients on them, are described in Table 3.

Crossrail is actively planning with TfL, Network Rail and the Transport Systems Catapult[11] what a digital railway will look like. We observed and participated in these activities through a series of policy discussions and workshops with users, focused on thinking about designing the digital systems that will underpin future railway operations. So, for example, great effort is being made to incorporate 4G mobile

[11] The UK's technology and innovation centre for transportation research: https://ts.catapult.org.uk

communications in stations and tunnels together with networks of sensors that monitor performance of the infrastructure and utilisation by passengers. In such an emergent area of technology, where there is uncertainty in how it will develop, there is a challenge in determining who is responsible for what, and dangers that, because of contractual constraints, key opportunities for innovation are missed. So, for example, parts of the track are on a steep gradient, causing considerable wear on tracks, wheels and brakes. The question arises of whose responsibility it is to build in digital intelligence for responsive maintenance: Is it Crossrail's, adding to its capital expenditure whilst reducing the operating expenditures for others? Or is it the rail track owner, the train manufacturer or service operator? Crossrail's approach has been to encourage dialogue on the whole issue of the digital railway and the role of innovation in it, to surface issues and converge expectations and plans.

For instance, a digital railway workshop was co-organized by Crossrail and the Transport Systems Catapult, including attendees from government (e.g. The Department of Business Innovation and Skills; InnovateUK), construction firms (e.g. Skanska; Costain), universities (e.g. Cambridge; Imperial College London), transport projects (e.g. High Speed 2; Crossrail), asset owners (e.g. Network Rail), railway operators (e.g. Transport for London), design firms (e.g. Arup), industry groups (e.g. the Rail Delivery Group; Future Railway), and co-operative research centres (e.g. Future Cities Catapult; Connected Digital Economy Catapult). The decisions these stakeholders make about a digital railway (e.g. the format used to store digital data) are highly interdependent and an open and collaborative approach is crucial to prevent a piecemeal approach emerging.

As another example of this high level of integration with clients, the Building Information Modeling (BIM) digital models used in the design of the system will be handed over to its operators. Wolstenholme, Crossrail's CEO, championed the adoption of advanced technologies such as BIM. BIM is a tool providing a digital representation of the transportation asset used through the life cycle from design and construction to handover, operation, and maintenance. Andrew Wolstenholme says: "For me, the value in BIM is not as a tool to co-ordinate the delivery phase, but for managing the lifecycle phase"[12]. Given its importance, the BIM group in Crossrail was brought into the innovation strategy umbrella.

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**Table 3: The Digital Railway**

**Digital Passenger:**
- Passengers able to access journey information and make informed decisions about routes, schedules, etc. throughout their journey.
- Passengers able to maintain connectivity with their networks, work and domestic, throughout any period of transition (i.e. movement) in their day.

**Digital Station:**
- Stations that support the needs of the passenger, ensure the most efficient transition with other systems and travel modes and which can be operated and

[12] New Civil Engineer, "Crossrail Half Way Major Project Report, 06/2014: p5

maintained in the most efficient and sustainable way.

**Digital Asset Manager:**

• A system that is automatically monitoring condition and component usage and responding with condition/risk based maintenance solutions that minimises down time and the presence of people on or near the railway.

**Digital Train Operator:**

• Trains that are as critical a component in the system monitoring and feedback system as they are as the principal means of moving passengers.

**Digital System Operator:**

• A rail system that is controlled centrally where appropriate, but whose sub-systems (trains, stations etc.) can communicate with and respond to each other in dynamic response to the users' demands.

• A system that can adapt to emerging technology and whose sub-systems have the capacity, principally band width, to accommodate new technologies and support renewal and upgrade strategies based on feedback information from the system.

• A continuum from requirement, through specification, design, manufacture, construction and into service all operating from the same information base.

Source: Crossrail

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## 5. DISCUSSION

Innovating strategically is challenging in all organizations, and is especially demanding in a complex transportation project such as Crossrail. Its partnership structure sees contractors that normally compete being asked to collaborate in sharing innovations, and getting their continued commitment to do so remains a challenge. Innovation strategy, furthermore, cannot be developed with a single client in mind. There is a highly complicated ownership and operating structure with which to engage. Crossrail's investment in innovation adds to its capital expenditure, while delivering operating savings to the railway's eventual clients. Nonetheless, the innovation strategy at Crossrail has had a cohesive effect, and has improved the performance of the project, which is on track to be delivered on time and on budget, as well as generating new innovations. Some of the features and successes of this approach can be explained by recourse to literature on innovation strategy.

### 5.1 Innovative capabilities

Crossrail's innovation strategy reflects and represents the dynamic capabilities of searching, selecting, configuring and deploying. The innovation system this strategy formalized did not emerge overnight. There was a focus on learning as it was trialled and prototyped, and its introduction has involved a series of training programmes with staff to entrench the recognition of its nature and value. Crossrail has systematized efforts put into searching for innovative practices, products and processes developed and utilized on other transportation projects, such as the Heathrow Express, Channel Tunnel Rail Link, and the Jubilee Underground Line Extension. The Chairman of the CIF, Terry Hill, was Technical Director of the HS1 Channel Tunnel project, highlighting this intention to learn from past projects. These innovations were often associated with changes in organizational structure, for

example, the development of an integrated project team and the early embedding of infrastructure owners (such as RfL) into Crossrail's senior management team.

The innovation strategy systematizes a selection process of which innovations to pursue, involving the integration of a range of people from within and beyond the organization in a transparent manner. It is the role of the Innovation Coordinators to manage this integration, a difficult and demanding role that has involved some staff turnover. This turnover may reflect the different challenges of the project over time. There is, for example, much more interest in environmental sustainability of operations in 2014 than there was two years earlier. A crucial function of the Coordinators is the management of the personal relationships around the development of innovations, contributing to changes in behaviour in the innovation programme.

Built into the selection process is an operational focus that brings in capabilities in configuration and deployment. Projects are not selected unless they have a functional sponsor and committed user keen to have the innovation applied. The role of the functional sponsor evolved over our three years of participant observation in key meetings (e.g. weekly innovation management meetings; quarterly innovation working group meetings). The trigger for this evolution was a growing realisation that the innovation programme could easily become a distraction defined by the pet projects of enthusiastic engineers. Another check on this tendency was the oversight of the senior executive group in the form of the CIF. They provided the stewardship required at the portfolio level to balance between operational focus and the higher-level strategic objectives. Central to this task was the articulation and codification of what the strategic objectives were; not just "delivering a world-class railway", but defining, concretely, what that means for people on the ground. The Innovation Director and Programme Manager and the CIF provide strategic oversight of the portfolio of innovation projects.

There is a strong focus on data collection and dissemination. Built into the system is a process of assessing successes and failures and feeding this information back in to the system. It is a process of learning to learn. It is also notable that besides the concern to learn from its own projects and from other transportation projects, there is also an appetite to learn from other sectors. Crossrail's 'open innovation' approach was based on learning from leading innovative companies in very different industries. There is recognition in Crossrail that leaving vast quantities of documents will not achieve the objective of building its legacy, and that an important component will be in connecting people with the expertise and knowledge to find and interpret the information collected. This also reflects a concern to overcome the difficulties of retaining knowledge in a labour market characterized by inter-project and inter-organizational job mobility.

### 5.2 Open innovation at Crossrail

All the players that can influence innovation at Crossrail constitute its 'innovation ecosystem'. The richness of Crossrail's innovation ecosystem reflects the different stages and rhythms of a major project. There are research inputs found in research institutes, such as Imperial College and University College London, those most

actively involved in designing and constructing the railway, and the eventual clients of the transportation system, with their appreciation of the needs of high levels of customer satisfaction and experiences.

One of the benefits of close relationships in open innovation is it can help mitigate the risks that can hinder progress. The OCI process, for example, was used to promote cost-saving innovation after the Government's Comprehensive Spending Review of October 2010 called for a major reduction in Crossrail's budget. Crossrail engaged in discussion with its joint venture partners about how to create a more efficient way of constructing tunnels and stations, and substantial savings were found by using an innovative technique. The close relationships with contractors and shared thinking about value creation and appropriation increased the probability of this happening.

The concept of open innovation was developed in the context of large, R&D undertaking, firms where Dahlander and Gann's (2010) four forms –acquiring, selling, sourcing and revealing - can be found. Most large transportation projects, and large infrastructural projects in general, have always relied on inbound acquisition and sourcing of innovations, with perhaps less focus on outbound forms. In Crossrail, however, revealing is an especially important component of the legacy for subsequent transportation projects. This is seen clearly in a conscious decision not to let concerns over intellectual property tie things up, and having a very open approach to its retention.

### 5.3 Lessons for future projects

It has been the intention of Crossrail to act as a test bed for future transportation projects, and to transfer experiences and learning. In July 2014, the Public Accounts Committee of the Houses of Parliament reported that: "Crossrail is a textbook example of how to focus on the essentials of programme management".[13] The Committee recommended to the Department of Transport that it captures lessons learned from Crossrail and apply them to other projects, such as the High Speed 2 (HS2) railway between London and Birmingham.

Around four people are currently involved in the early stages of learning legacy discussions with HS2. It is argued within Crossrail that the lessons should progress beyond the transfer of lessons about managing costs and use of methodologies and should encompass cultural change within the supply chain to encourage innovation.

A major method of transferring lessons is the transfer of people, and Crossrail staff maintain close contact with ex-employees, such as Andy Mitchell, who is now CEO of Thames Tideway, another major infrastructure project. Links are also developing with the Transport Systems Catapult, a major UK government initiative to facilitate connections between research and business. Crossrail, again in conjuctions with the Transport Systems Catapult, is planning an innovation legacy initiative.

## 6. CONCLUSIONS

[13] Public Accounts Committee, Eighth Report of Session 2014-15, HC 574

As Ward (1984:288) noted about transportation innovation: "There is no universal prescription for success". The nature and risk of each large transportation project is essentially idiosyncratic. Nevertheless we believe there are lessons Crossrail holds for improving innovation outcomes in complex transportation systems. Key amongst these is approaching innovation strategically and ensuring strategy applied to the project connects with future operational requirements.

Creating and deploying an innovation strategy is a dynamic process in such complex organizational and contractual circumstances. The scale and operational life of transportation systems requires approaches to innovation to be evolving and adaptive. Emphasis changes over time in Crossrail, for example, with its focus on civil to railway/mechanical to digital engineering. Innovation strategy is undertaken iteratively and informed by learning, drawing on evidence from the external environment, and appraising internal resources, capabilities, and processes, to build, supplement, and organize an organization's innovative capabilities in a changing environment. It involves the active participation of leaders, middle-level managers and the people behind new ideas and their champions. It involves a formalized process and a clear articulation of the why, how and when of innovation.

Developing the innovation strategy was delayed, and it is an open question what influence it might have exerted if it was operationalized earlier. There is a constant need to reaffirm the commitment to the strategy by the various partners, and ensuring their financial contributions is key to this buy-in. It also requires continual emphasis, not allowing the innovation agenda to diminish as the project moves towards completion.

Delays and tensions are inevitable given the complexity of the project and its technical demands, but there has been value in having a defined process for evaluating innovation that helps shift decision making from ad-hoc to planned and strategic. This is a better way of justifying and allocating resources with lessons for future transportation systems. In the past the elements of open innovation were undertaken as one-offs. Innovation strategy provides a language, concepts, tools, and common ground for integrating innovation. Innovation in Crossrail is localized but its strategic approach generalized it to the benefit of the delivery and planned operations of the transportation system.

Innovation strategy succeeds when it is not simply the responsibility of a few key people but, in the words of the ex CEO of IBM, Lou Gerstner, it becomes part of the DNA of the organization (Gerstner, 2002). Collaboration is a central organizational behaviour needed to be innovative, and Crossrail's recognition that its success in delivering a world-class railway lies with pulling in, sharing and using ideas from outside of its boundaries as part of everyday behaviour is crucial.

This study raises a range of further research questions. Examination of innovation strategy in other transportation systems would help overcome the challenge of generalizing from case studies. The question arises of whether the lessons from this transportation system are applicable in other systems, such as airports, or other large infrastructure projects in general. By examining the significance of innovation strategy in a large transportation project it might be hoped that such projects could increasingly become research sites for management and innovation scholars, whose current focus tends to be limited on large, R&D undertaking firms. There is also a

range of public policy questions warranting exploration. For example, it would be interesting to explore the costs and benefits of the approach of not seeking pecuniary open innovation advantage by selling intellectual property developed in the course of such projects.

In contrast to many large and complex infrastructure projects, whose non-performance has attracted the concern of the UK's and other governments, Crossrail is on track to deliver on time and on budget. Innovation has been crucial to this achievement , but there are grounds for much greater and more detailed analysis of the various financial and operational returns to all the component elements of the innovation strategy and of the overall contribution of the strategy itself. Further consideration might also be given to how such iconic projects can broker and encourage innovations from small, entrepreneurial firms.

Ward (1984) offered many profound insights into the challenges of innovation in transportation projects, and perhaps none more so than his observation in the USA that 'low-risk, quick payoff projects' drive out 'more ambitious but less certain technical goals" (1984:287). As he says, transportation innovation is crucial to the fabric of technological progress in society. The lessons about the strategic approach to innovation analyzed in this paper can therefore be argued to have broader consequences than the hugely significant outcome of better railways.

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