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Crossrail Innovation Programme – Innovation Evaluation Report

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EXECUTIVE SUMMARY

Crossrail is a large infrastructure project creating an east-west railway line across London and its surroundings. The line will be 73 miles long including 13 miles of underground line under central London. Crossrail brings together numerous contractors working over a dozen of sites. In such a networked enterprise, a top-down approach to innovation is impossible and promoting innovation in such a context requires an innovative approach. The innovation programme was instigated to answer the challenges to innovation posed by the structure of the Crossrail programme, the aim of which is to foster, support and diffuse innovation and best practices across sites and across contractors.

The programme ran for 3 years, so was only active for part of the overall project. Imperial College London was invited by Crossrail to study the programme during its existence and was commissioned to evaluate the benefits associated with its running. Those benefits are related to efficiency, improved collaboration, welfare and health and safety, implying that on top of the financial benefits associated with some innovations, there are also intangible benefits. It is very likely that those intangible benefits, which are hard to quantify in financial terms, are larger than the financial benefits. This is in part due to the short time during which the programme was active, meaning that many of the financial benefits come from innovations that improve efficiency and allow cost-saving in the programme, rather than radical innovations that change the way a portion of the work is carried out. Indeed, there are a small number of high potential innovations in the

Crossrail pipeline that are reaching maturity too late for the programme to fully benefit from them. This leads to two main conclusions; first, an innovation programme should be run from the start of the work, or even prior to the beginning when contractors for the project are identified. The benefit to Crossrail of running the programme are more limited than they could have been as the programme did not come online early enough; Second, intangible benefits are one of the main outcomes of running such a programme and their importance should not be underestimated. Below are the main evaluated benefits of the Crossrail Innovation Programme:

- In estimating benefits of the Crossrail programme, three scenarios were developed. The benefits are estimated at £3.5 million for the baseline scenario, £2.7 million for the pessimistic scenario and £5.4 million for the optimistic scenario. These benefits are calculated as of June 2015, without projection to the end of the programme.
- There are a number of intangible benefits, such as Health and Safety improvements, and additional behavioural benefits associated with an innovative culture, such as increased collaboration and team building which should not be underestimated, and are arguably as important as financial benefits. However, those intangible benefits were not included in the monetary calculation as the industry has no standard assessment tool for intangible benefits. This reduces the receivability of any custom made estimates and for this reason, we choose to exclude them from our financial figures.
- Innovations which show potential should be monitored and evaluated when usage starts and at regular intervals over the period of use. The Six Sigma framework is one potential tool for such a task and allows for a more fine-grained capture of benefits as well as more reliable estimates. Ideally, a programme will focus more on breakthrough innovations in the early

stages of the project and progressively shift its focus to supporting implementation through incremental innovations that provide efficiency gains.

- It is important to have mechanisms in place to seed more radical innovations, such as the innovation competition that the Crossrail programme has been running. However, it should be expected that radical innovation needs time to mature, and therefore many only offer returns 3 or 4 years down the line. Thus, to benefit fully from a mechanism seeding radical innovations, it is important to start the innovation programme as early as possible. Alternatively, it would be necessary to run an ongoing programme at industry level.
- Legacy and research innovations are important, but benefits from these do not accrue to Crossrail, which reduces the incentive to pursue that type of innovations. Instead, an industry level programme would be necessary to complement project specific programmes.
- In an organisation like Crossrail, which coordinate several organisation around several linked projects, dissemination of best practice is crucial. An innovation programme can enable efficient and timely dissemination. At the level of the contractor, being the sole user of an innovation can be a competitive advantage, but the project benefits if an innovation is used in every case where relevant, regardless of the contractor. For this reason, Crossrail benefits directly from dissemination, while somehow eroding the individual competitive advantage of contractors (for work outside the programme). However, this competitive advantage erosion might have positive outcomes at the industry level by increasing pressure on contractors to innovate in order to restore competitive advantage. Thus creating the conditions under which the pace of innovation may accelerate in the industry.

INTRODUCTION

Innovation can be defined as the commercialisation of new ideas bundled in products or services. In today's economy, innovation is not merely option but a vital component contributing to the success of companies. There is ample evidence that innovation plays a crucial role in firm competitivity and survival, yet most competitive advantage today is temporary and the ability to innovate over time is one of the main way firms can maintain their advantage over competitors.

However, Crossrail is a temporary organization (with no revenues) focused entirely on delivering an asset—an operational railway—and as such its own demise is one of its objectives, putting Crossrail in a unique situation regarding innovation. This is further reinforced by the fact that Crossrail is partially funded by taxpayer, so it is legitimate to ask whether the imperative for innovation applies to Crossrail. One way to interpret this is to consider that the imperative applies at the contractor level and Crossrail should trust that the competitive forces facing the contractors are sufficient incentives for them to innovate over the life cycle of the Crossrail project. An alternative view is to recognize that while contractors have an incentive to innovate, Crossrail can play a role in steering this innovative effort in directions that will benefit both the project and the industry at large. This report embraces the second view and postulates that large infrastructure projects, such as Crossrail, do shape innovation in the construction industry. This leads to the following questions: how best can Crossrail leverage its unique position as the client of a large infrastructure project and what are the particular challenges of encouraging and supporting innovation at Crossrail?

Crossrail decided to create an innovation programme which started in 2012, to coordinate, diffuse and support innovation across the project. This document presents a framework to evaluate

innovation at Crossrail and proceeds to evaluate the benefits associated with the innovation programme. Finally, it presents a series of findings and makes recommendations for future similar programme based on the Crossrail experience.

SCOPE

This document is separated into three main parts; the first presents the innovation programme at Crossrail, known as Innovate 18, outlining how innovation is organized, what the programme does and how this fits with Crossrail's supply chain structure - where several contractors are delivering different parts of the programme. It also highlights the programme's key achievements.

The second part of this report estimates the benefits of innovation at Crossrail. It briefly describes the value of evaluating innovation, along with the resultant challenges of doing so. It then describes the process and method used to evaluate the innovations submitted to the Innovate 18 platform, and then proceeds to associate benefits with three categories - financially quantifiable benefits, where we present estimates for three different scenarios (a baseline, an optimistic and a pessimistic one), health and safety benefits and intangible benefits derived from running the innovation programme.

The third part of the report presents conclusions, recommendations and benefits of running an innovation programmes within large complex organisations such as Crossrail. One key lesson from the Crossrail experience is the importance of building regular evaluation into the process of running the programme, to be able to identify high potential innovations, but also to facilitate internal consensus about the benefits of innovation in such a context, as well as outlining some of the pitfalls encountered when evaluating innovation. Finally, the report suggests some adjustments

to the programme's processes for registering, managing and evaluating innovations. Lessons learned from the innovation programme provide a good basis for reflection on the implementation of future innovation programmes.

WHY INNOVATION MATTERS

The world has experienced unprecedented economic growth since the beginning of the industrial revolution (Baumol, 2002). Many different factors play a role in this growth, but innovation in a number of domain was key, such as progress in manufacturing technology and improvements in medicine. Indeed, economists widely agree that the engine that fuelled this growth is innovation (Baumol, 2002; Solow, 1957, 1994), defined as the introduction of new product and services which can be commercialized and have transformed the world beyond recognition. In many industries, "innovation has replaced price as the name of the game" (Baumol, 2002). In other words, for many organisations, innovation is crucial for survival. Baumol's affirmation that price is not at the centre of competition anymore is worth seriously considering as implications are significant, because it means that using innovation, some firms can maintain a competitive advantage through differentiation that allows them to consistently charge a price premium (for example, Intel has dominated the CPU market for PCs for the past 3 decades despite the competition of AMD cheaper processors). But it also implies that short of differentiation, firms will immediately lose to discount competitors.

Crossrail is not a traditional organization, however, and theoretically the temporary nature of the project should make innovation less of a concern for Crossrail. Yet, Crossrail is in a singular position to pilot and benefit from innovation and in doing so, can help the construction industry accelerate the pace at which the industry innovates and lead the way for the next UK mega project.

We argue that the managed system implemented by Crossrail could benefit other infrastructure projects.

INNOVATION IN INFRASTRUCTURE PROJECTS

Large infrastructure projects are usually delivered by a network of contractors who are direct competitors in the industry, and find themselves collaborating closely within the project, through joint ventures and associations.

This unusual setting illustrates both the challenges and the opportunities available to Crossrail when it comes to framing innovation within the project, and for the industry at large. As Crossrail is not competing with any other large scale projects, it does not need to survive, preserve or increase market share. Nonetheless, Crossrail can benefit from innovation during the programme delivery, and direct contractors innovative efforts to a certain extent, while ensuring that suitable innovation is diffused across the programme. In addition, as a public organisation funded by the government, innovation within Crossrail will increase the quality of the delivery as well opportunities for lower costs with spillovers from innovation benefitting future projects (Baumol, 2002; Owen-smith & Powell, 2004), indirectly aiding the the UK public. For those reason, Crossrail should do its best to foster innovation by working with contractors, help identify crucial innovations and ensure that they are utilised and captured.

PART 1: INNOVATION AT CROSSRAIL

THE INNOVATION PROGRAMME

Crossrail's programme adopts an open innovation approach. Henri Chesbrough argues that through the use of both internal and external ideas, as well as internal and external paths to market, firms can more rapidly advance their technology (Chesbrough, 2006). In the spirit of Chesbrough's definition, the innovation programme at Crossrail aims to create an innovation ecosystem around itself and to foster collaboration among contractors. The programme has several missions; for the team to network and communicate the understanding of innovative activities that take place in different sites; to share and publicise these activities and to facilitate collaboration onsite through its multiple connections. It runs the Innovate18 platform where every employee can submit innovative ideas, which it evaluates and when relevant, helps individuals to prepare an entry for the innovation competition. The innovation competition allocates funding among candidate project on a regular basis with the aim of helping further developments of innovation that would not happen otherwise. The investment made through the competition leads to a portfolio of invested projects. All of those tasks are performed by the 5 team members of the innovation programme.

Crossrail developed a network of contacts across all sites and contractors on the project to raise awareness of the programme and used this network to collect innovative ideas and provide support to employees in submitting them to the Innovate18 innovation platform.

The team then evaluates the innovations to decide which ones should be published on the platform, which requires additional work to be useful, and which need financial support to be realized.

Finally, they determine which ideas are "parked" because they are either duplicates of existing innovations or contain too small an innovative step.

This process requires members of the team to develop a broad set of skills to recognize and nurture potential innovations.

Contractors innovation

Contractors on the programme have their own innovation programmes and R&D facilities. Nonetheless, a significant amount of problem-solving activity takes place on site. Issues arise that were not anticipated in the design phase, opportunities are identified and creative solutions allow the work to proceed (and sometimes to be completed) faster than anticipated.

The main concern with innovation taking place on site and lead by contractors is that contractors do not have any obvious incentives to share the ideas with others, including the mega-project parent. Indeed, their business model relies on maintaining a competitive advantage over their competitors, which can be achieved through maintaining a technological edge. This is the challenge that the innovation programme needs to overcome: help to encourage open innovation practices at different contractor firms, and how can this problem-solving activity be captured, codified and diffused for Crossrail to benefit from it?

Innovate 18

The programme runs two platforms to accept innovation submission and publicise them. The information management system is used by the innovation programme team to accept submissions of ideas and evaluate them. This allows employees of contractors and of Crossrail to submit innovation ideas which describe how they have tackled a specific problem within their role on the

project. Consequently, those ideas cover a broad range of problems from simple time saving ideas to whole new ways of carrying out a specific part of the works. Innovations deemed publishable are then shared on the Innovate18 portal, accessible by all employees on the project. This covers the whole scope of potential innovative impact: from very incremental refinement of existing tools or processes, to brand new ways of solving a specific problem. Innovate 18 has been very successful with over 800 innovations submitted to the platform since it first went online in 2013 with the support provided by the innovation programme team contributing to a high level of engagement with the platform.

Innovation competition

The innovation competition aims to promote the submission of early stage ideas to the platform by offering the possibility of financial help to further develop the idea and in doing so overcomes one of the challenges faced by innovation submission platforms which is a tendency to mostly receive submissions for incremental innovations.

Building a collaborative and innovative culture

The work of the programme has a major impact on the culture of the organisation. Modern organisations face the challenge of motivating their workforce and increasing productivity. The recent trend of slow productivity growth in the most advanced economies has many sources. One of them is the disengagement of the workforce, which prevents individuals from questioning processes in the workplace (Pech and Slade, 2006). By making employees feel that their input about how to improve processes is valued, it creates tremendous opportunity to unlock workforce productivity, but organisations have to find ways to engage with their employees and motivate

them, and one way to do this is to give them ownership of the processes they handle. If employees feel that they can contribute to the way the work is conducted, while maintaining health and safety standards, then the organisation unlocks potential productivity gains. This is especially true for complex tasks where the individual carrying out the work is best placed to refine processes. And indeed, many innovations within Crossrail are user-led in the sense that the impetus for innovation comes from difficulties faced by workers in the completion of their work.

Encouraging innovation diffusion: innovation brokers

The innovation programme team and the innovation champions in each site have a crucial role to play in the diffusion of innovations. They act as brokers (Burt, 1992), which means that they bring together unconnected individuals from different sites working on similar innovations. In addition, they are in a great position to spot potential recombinations of ideas as they have a birds-eye view of innovation across sites (Burt, 2004; Schumpeter, 2000).

Being able to bring people together and recombine ideas means that the programme team is crucial for the success of innovation at Crossrail. Indeed, it increases the rate at which innovations are generated and fosters new collaborations (Obstfeld, 2005). The centralised programme team supported by the site specific champions helped establish, diffuse and reactivate the message that, for Crossrail, innovation matters.

PART 2: INNOVATION EVALUATION

BENEFIT AND CHALLENGES IN EVALUATING INNOVATION

The purpose of evaluating the innovation programme at Crossrail helps us to better understand its impact on the delivery of the works. In addition, it will highlight the value and types of benefits captured by the programme. This will also provide some guidance for future innovation programmes.

Because innovation is about change, it is sometimes difficult to understand its impact immediately. From a financial perspective, benefits of incremental innovations, innovations that refine an existing process, are easier to evaluate because there is a clear baseline against which to measure the innovation. More radical innovations are usually harder to evaluate. Often, it is less clear what the baseline should be, especially if the innovation leads to the creation of something that could not be created before. For this reason, one has to adopt a multiperspective approach that considers both the monetary and intangible benefits of each innovation.

METHODS

The evaluative data was collected from visits to some of the Crossrail sites and from documents available within Crossrail. The main challenge of this evaluation was sourcing the data, indeed, the nature of the work on Crossrail implies a high turnover among the contractors' workforce and as a result, there is often no continuous record associated with usage at different stages of the project. This has complicated evaluation because it is difficult to know how much the innovation

was used or precisely evaluate the efficiency gains associated with the innovation over its life-cycle.

This challenging data situation means that one has to be pragmatic and accept that the estimate will have a different level of certainty depending on the quality of data available for a specific innovation. In order to reflect this limitation, we developed a scale to rate the financial certainty of the innovation. This scale goes from 0 (no data) to 5 (high level of confidence).

This variation in confidence has to led to the development of three separate scenarios for evaluating the benefits. Based on the estimated confidence level of the baseline scenario, the pessimistic and optimistic scenario will receive a different value representing the uncertainty in the estimate.

The data challenges that were mentioned made it impossible to evaluate some of the innovations, while at the time of the evaluation, some of the sites were completing construction and therefore could not be easily accessed. In total, 299 innovations were reviewed in preparing this report, representing about 70% of the total number of innovations published in March 2015 on the innovate 18 platform (423), out of a total of over 800 ideas submitted.

FINANCIAL ESTIMATES

Scenarios

In order to account for uncertainty in the estimates, we developed three scenarios for the financial benefits associated with each innovation. The baseline scenario is defined using on site interviews and additional documentation where available (e.g. technical reports). The pessimistic and optimistic scenarios utilise the baseline scenario and other information collected through the

interviews. Those additional two scenarios allow us to incorporate uncertainty, for example when the duration of the innovation's use (e.g. Clamshell excavator) is uncertain. In such cases, the pessimistic scenario uses the smallest amount of time for which there is evidence of usage and the optimistic scenario uses a longer amount of time, based on the available evidence, finally the baseline scenario uses a duration that falls between the minimum and maximum. Usually, the baseline scenario is determined first and the pessimistic and optimistic scenarios are determined in relation to the baseline and additional information about the innovation. This allows us to take into account uncertainty about length of use, as already stated, but also uncertainty about the speed at which benefits from this innovation are realized. When there is no information, the pessimistic scenario is 50% of the baseline and the optimistic scenario is double the baseline. These ratios are meant to provide an indication of the uncertainty surrounding the innovation.

At the time of the evaluation and without projection to the end of the programme, the total benefits of the innovations evaluated are quantified as £3,580,824 for the standard scenario. For the pessimistic scenario, they are £2,726,642 and finally, for the optimistic scenario, are £5,440,797.

Distribution of benefits

The distribution of benefits shows that most innovations have small benefits (<£1000) – this is perfectly normal and to be expected. It might be argued that innovations with small benefits should constitutes the largest pool of innovation as they are often very low cost to implement.

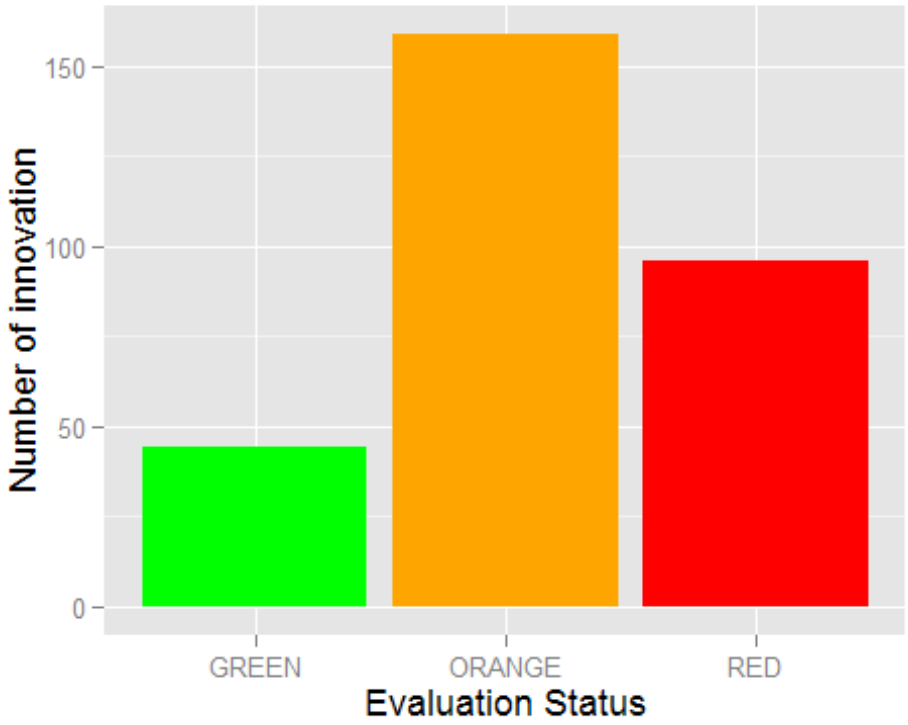
Table 1: Number of innovations by benefit category

Benefits	Standard	Pessimistic	Optimistic
<£1001	195	197	189
£1001-£10000	28	35	17
£10001-£100000	27	19	38
£100001-£200000	4	2	3
£200001-£500000	3	3	3
£500001-£1000000	2	1	4

Innovation status and confidence level of the estimation

Each innovation was allocated a status based on whether or not the innovation was reviewed and if it was, how much information was available and how precise that information was.

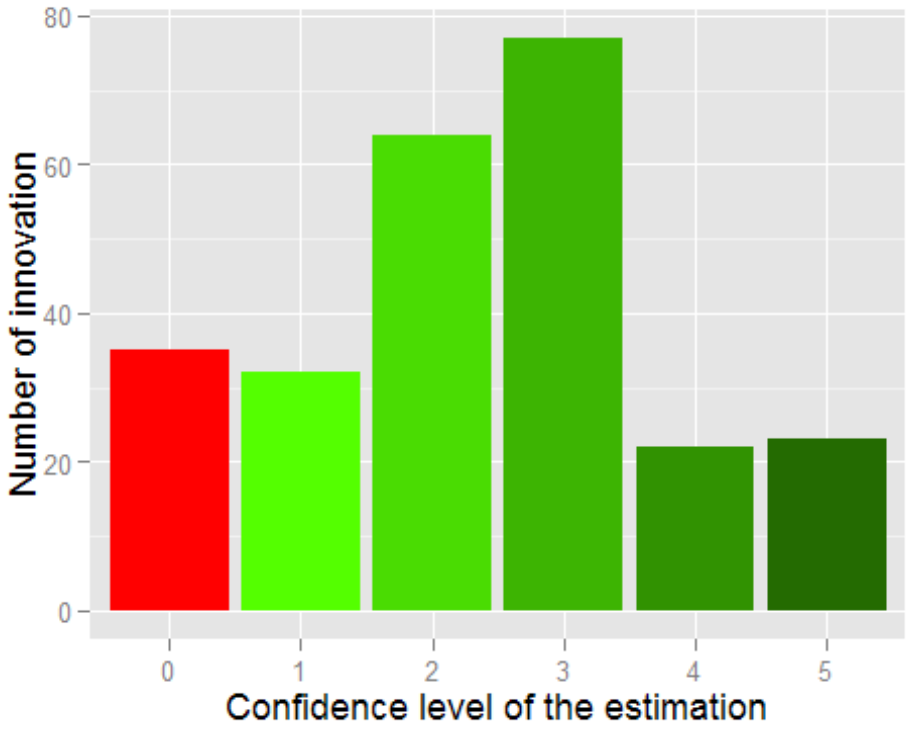
Figure 1: Number of innovations by evaluation status



This plot illustrates that for about one third of the innovations reviewed, it was not possible to find any information about the use of the innovation on site, thus it is difficult to provide estimates of benefits, illustrating how crucial it is to build the capture of benefits into the programme. For about 50% of the innovations reviewed, there was some data available but some uncertainty remained about the length of use of the innovation or about the precision of the benefits estimate. For the remaining 20%, the data was of high quality and the estimates are precise, yet a significant portion of these yield no or small benefits (for example, INV00081, Wireless mobile gas monitoring for excavation for which the trial concluded that it was too expensive and therefore it was not used). The status is a coarse measure of the availability of information for a specific innovation.

To complement the status of an innovation, we develop a confidence level scale that evaluates how precise the estimates are deemed to be. Confidence level are related to the status but refine the initial assessment after the data has been gathered and the model finalised. This assessment rates the innovations in terms of the confidence in the precision of the monetary evaluation. The rating is on a scale from 0 to 5 with zero meaning that there is no certainty in the evaluation. Innovations that have a certainty level of 0 see their benefits counted as £0. It is possible that some benefits existed, but they could not be captured with sufficient precision.

Figure 2: Number of innovation by confidence level

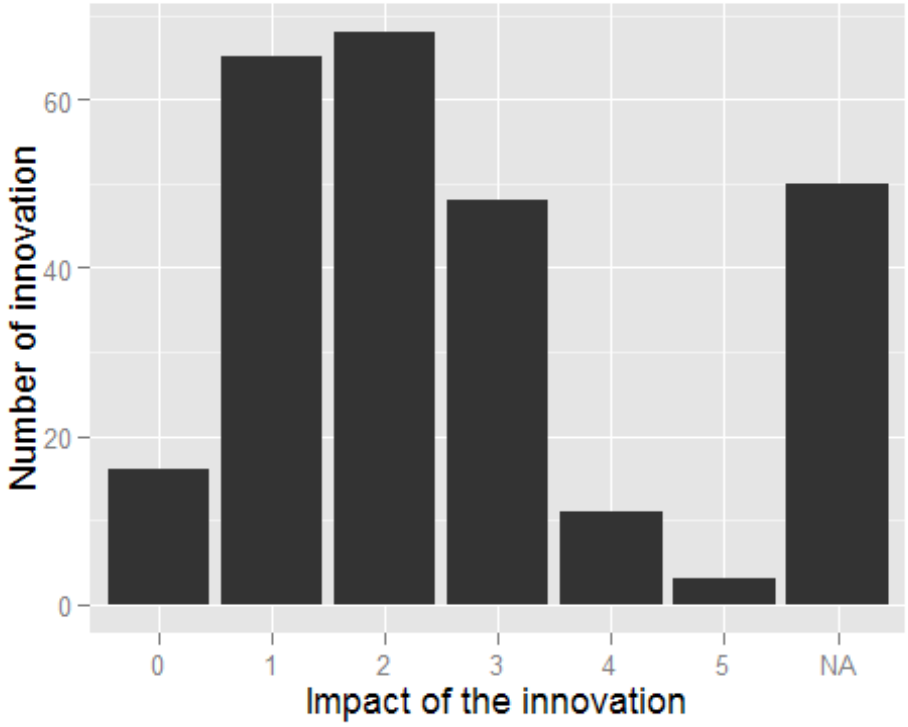


The confidence level plot shows that a lot of innovations have high confidence levels (3 and above). However, there are also about 130 innovations with a low level of certainty, reiterating the benefits of building the evaluation of innovation into the processes of the innovation programme. Conducting the evaluation on an ongoing basis would greatly improve the precision of estimations.

Impact

Some innovations might represent a significant change in the way the work is carried out and yet be very hard to quantify in monetary terms. To overcome this limitation, we developed a scale that measure the impact of the innovation on the works.

Figure 3: Number of innovations by impact



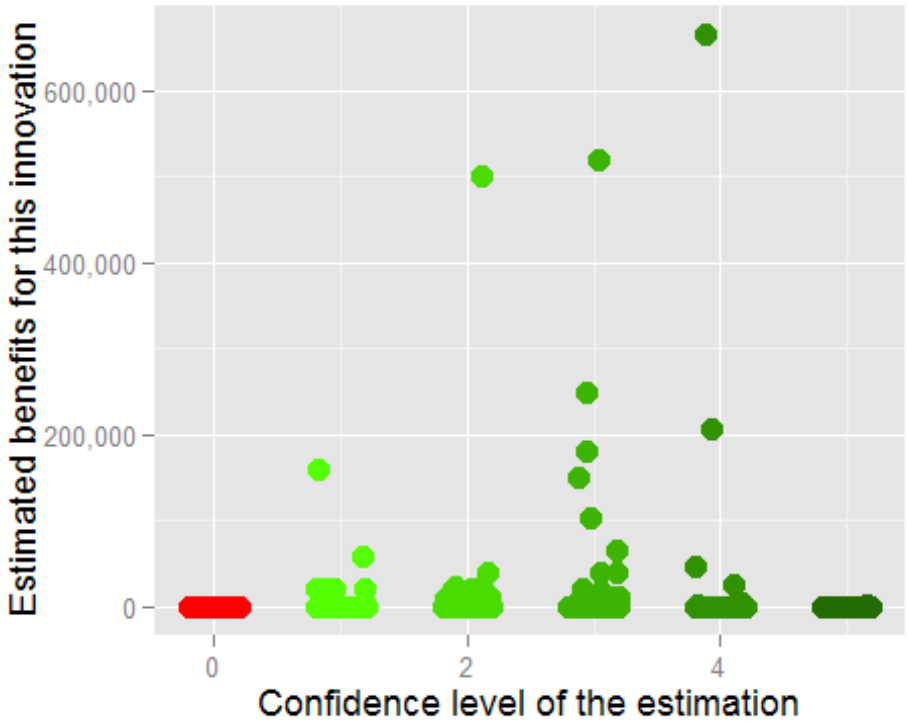
The scale rates each innovation on a 0-5 scale, with zero denoting an innovation with no impact (for example, because it has not been used) and 5 an innovation with a large impact (for example, the site gantry crane at Custom House (INV00626) that has allowed the work to proceed in a completely different fashion than would otherwise have happened.

The distribution of impact is skewed towards innovation with low and moderate impact. This is normal and should be expected from an innovation programme. Only a very small proportion of innovation will generally have a large impact on how work is carried out, which is amplified in temporary organizations like Crossrail because there is only a short period in which the innovation can be used, thereby limiting the discovery of additional uses which could increase the benefits associated with a single innovation.

Benefits, confidence and impact

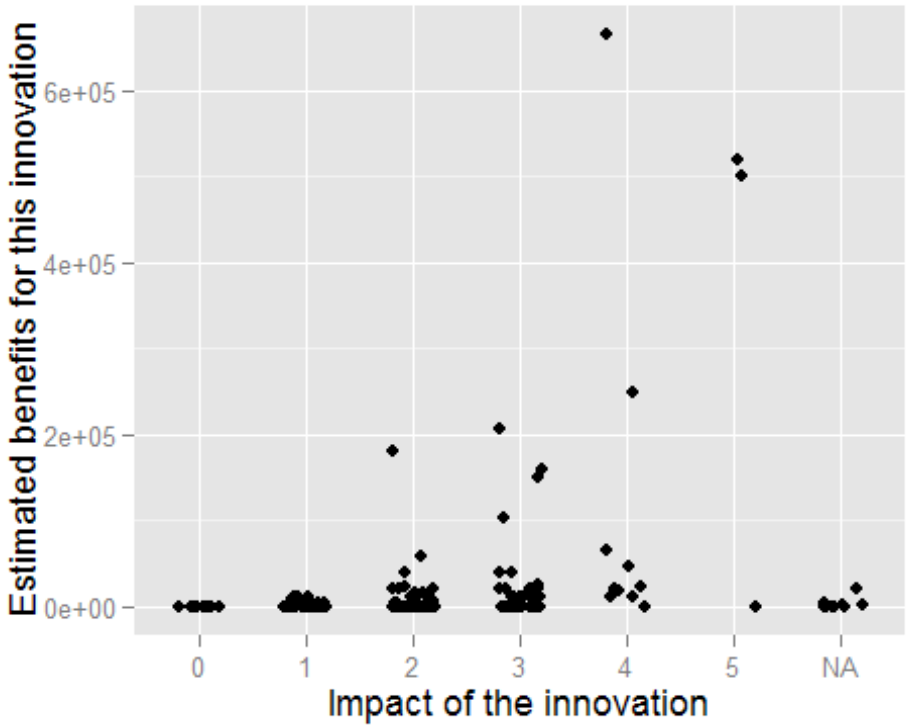
In this section we examine some of the relationships between monetary benefits estimates and levels of confidence and impact. When plotting the estimated benefits against the confidence level of the estimates, one can see that, overall, innovations with the largest benefits have moderate to high levels of confidence for the estimates (between 3 and 4).

Figure 4: Benefits for an innovation by confidence level



The same pattern is visible when plotting the estimated benefits against the impact of the innovation.

Figure 5: Benefit of an innovation by impact



Note on financial estimates

The estimates presented above are conservative. A lot of innovations which have small efficiencies attached to them have seen their total benefit set to zero in all three scenarios due to low level of certainty. We deemed it preferable to risk underestimating benefits than overestimating them. Adding these innovations for which data is scarce would increase the "noise" in the estimation and potentially incorrectly inflate it. However, it is very likely that some of those innovations (193 innovations have £0 benefits in all three scenarios) have in fact some advantages meaning that the potential benefits from those innovations could significant. In addition, the primary motivation of health and safety innovation is not monetary benefits, so those innovations have not been included in this count. Finally, in addition to monetary benefits, there are intangible benefits associated with

most innovations, and these are not adequately captured by the monetary estimation. In order to remedy this limitation, the following two sections attempt to give an overview of health and safety benefits and any intangible benefits that are associated with some of the innovations recorded.

HEALTH AND SAFETY

Many of the innovations gathered by the innovation programme focus on the health and safety needs of the workforce or the public. In terms of the monetary evaluation we conducted, their direct monetary benefit is often equal to zero, because there is no precise way of measuring the benefits of the innovation in terms of reduction of risk. However, there are often significant non-monetary benefits associated with such innovations, summarised in this section

There is a wide variety of health and safety innovations published on Innovate 18, with a wide variety of benefits. Some improve safety in the execution of the work - for example, the Hookcam (INV00406) sharpens the awareness of crane operators by letting them see the surroundings of the load they are carrying. In doing this, not only is efficiency improved, but it aids safety by removing blind spots for the crane operator. Another example, changing people and places (INV00465) raises awareness of how other people work, showing that machine operators do not always see well all around them and making others aware of this helps to mitigate risk. The suggestion of staircase access to shaft (INV00653) speeds up access to the site and secures it, while also allowing for faster evacuation in case of emergency.

All those innovations have no direct financial benefits beyond minor efficiency gain (e.g. Hookcam, stair access), but they arguably have large intangible benefits in terms of helping reduce the potential for accidents on site.

Usefully the implementation of these innovations sends a valuable signal that the project cares about workforce welfare. There are spillover benefits arising from this, such as higher motivation which leads to improved productivity.

Other health and safety innovations are directed at the general health of the workforce, such as the defibrillation training (INV00327), or free dental check-ups (INV00313). Again those innovations have no direct monetary benefits but intangibly raise morale and higher morale has been linked to increased productivity (Rosenbaum & Rosenbaum, 1971).

The added benefit of such a focus on health and safety is greater engagement of the workforce in their own safety, increasing the likelihood that hazardous practices will be reported and corrected, further mitigating the risk of a larger incident.

INTANGIBLE BENEFITS

There are pervasive benefits associated with innovations that do not lend themselves to monetary evaluation. For example, as already mentionned, health and safety innovations are likely to have benefits beyond health and safety by raising morale. Similarly, an innovation that makes the work more efficient might also contribute to team building which in turn can increase average worker productivity.

Beyond the intangible benefits associated with specific innovations, there are more encompassing soft benefits associated with the existence of the wider innovation programme, as it encourages the diffusion of an innovation culture throughout the organisation. This developing innovation culture is apparent through the number of submission to the Innovate 18 platform, and implies that workers are more likely to adopt a problem-solving approach to their jobs so instead of doing their

work as prescribed, they are more likely to apply critical thinking and identify how they can improve processes. Such benefits are hard to capture because most of the problem-solving efforts address issues that are too small to be reported on the Innovate 18 platform, but it is highly likely that there are large benefits associated with a problem-solving culture.

PART 3:

In the third part of the report, we highlight our main findings and two types of recommendation; the first applies directly to the Crossrail innovation programme and the second more generally to the running of innovation programmes within large infrastructure projects.

FURTHER WORK ON INNOVATION EVALUATION AT CROSSRAIL

Our evaluation of the Crossrail Innovation Programme focused on covering as many innovations as possible; consequently that breadth sometimes had to be prioritized over depth and some benefits estimates could be refined with more time. However, a fundamental limitation of the work is that for a significant proportion of innovation, data was hard to source as both the innovator and people who used the innovation have moved on. This is a particularity of the work done at Crossrail where innovations are often used temporarily for a specific task, and of the reasons why the diffusion role of the innovation programme is so crucial. A more fruitful approach to evaluation, already adopted by the innovation programme, is to monitor high potential innovations more closely as they come into the system, therefore embedding the benefits evaluation into the innovation programme. This would greatly improve the quality of the data available for future evaluations.

This highlights why the design of key performance indicators (KPIs) is crucial. If KPIs include the need for financial estimates from the outset, it means the development of measurement tools. This also highlights the need to adapt the innovation programme to extract as much value from the innovations when they are in use, which can be achieved, where possible, by diffusing the innovations across sites for specific parts of the work.

RECOMMENDATIONS FOR THE CROSSRAIL INNOVATION PROGRAMME

Embedding the evaluation of innovation in the programme

As mentioned earlier, the innovation programme should monitor selected innovations for potential benefits as they come into the system. This has the potential to make the evaluation of innovations more accurate because measurements will happen as the innovation is being trialled and implemented, rather than retrospectively. This is particularly important in a project like Crossrail where innovations are only used temporarily.

Additional benefits could be captured by measuring the attitudes to innovation of key individuals (within central Crossrail, but also on site) using a survey tool to measure how much collaborative interaction individuals have within their site and across the programme. Coupled with monitoring the number of innovations submitted by certain sites, this could be used as a tool to inform the project about where efforts should to be focused, allowing resources to be redeployed on the sites that need to engage more with the Innovation Programme.

Finally, trying to measure collaboration across organisations boundaries (through a survey) could help firms to understand where the benefits of the innovative culture are most salient, as well as

understanding what makes certain sites more collaborative so as to allow the reproduction of this dynamic at other less innovative sites.

Innovation evaluation needs to be carefully designed

Innovation programmes should have processes in place to monitor their performance. However, there are risks associated with the evaluation of innovations, particularly in potentially influencing behaviour by developing perverse incentives for innovators. Indeed, if the focus of the evaluation is too strongly on short-term monetary savings, this may result in less radical innovations that, despite clear monetary benefits, have limited impact on the works (e.g. an automatic monitoring system that allows night surveyor cost savings). This in turn might lead to reduced benefits from innovation over the life of the programme because the balance will be tilted too far towards incremental innovations.

Bu at the other extreme if the focus of evaluation overtly favours radical innovation then easily obtained benefits from incremental innovations risk being overlooked. It is a difficult balance to find, but one that should change over time, from a focus on more radical innovations at the beginning of the programme to more incremental ones towards the end.

So, in terms of designing such an evaluation, several things need to be considered. First, it is possible that innovations which at first do not appear to have a high potential are revealed to be more impactful during trial or after modifications. Second, innovation with obvious financial benefits are often the most incremental, and while they improve efficiency and are important, they often do not lead to radical performance-enhancing breakthroughs. Indeed, in the early stages, radical innovations tend to perform less well than incremental one. The advantages of radical

innovations are only revealed over time when it becomes obvious that the technological path which the radical innovation opened has a high potential for performance improvement. This leads to a crucial conclusion: to allow for more radical innovations to be pursued, the programme must take risks and be resilient to failure. It should not be a surprise that a large proportion of the innovations submitted to the platform have no monetary benefits. The proportion of innovations with benefits could also be used as a measure of whether the programme is taking enough risks. If too large a proportion of innovations have modest benefits, it would be a sign that the programme is underperforming and only pursuing "safe bets", while should the proportion of innovations with no benefits rise above 90%, it is an indication that the programme is taking too many risks and may need to be refocused to more incremental innovations. If the the firm incorporates evaluation into the programme, it can potentially measure whether the degree of risk being undertaken against programme targets. That level of risk is then likely to vary over the course of the programme from a pretty high level to a lower one as the works reach completion. The inherent risk associated with innovation should not deter investment in the innovation programme. In the present analysis, most benefits have come from 20 to 40 innovations of the 800 submitted to the platform (or between 2.5 to 5%).

Open innovation

The Crossrail programme has adopted an open innovation approach using the innovation submission platform. As outlined above, utilising open innovation practices means that the innovation programme at Crossrail has the potential to initiate a virtuous cycle in which each contractor has to strenghten their investment in innovation to retain a competitive edge which quickens the overall pace of innovation in the industry.

The main threat to this cycle is the disappearance of an entity like the Crossrail innovation programme. Indeed, without such an entity in contact with major players in the industry, it is likely that the pace of innovation would quicken for a short period of time, then slow down again.

Initiatives like the Crossrail innovation programme have the potential to help transform the construction industry, but in order for this to be an industry changing event, the models, platforms and strategies developed here must be adopted by other large infrastructure projects, while promoting a similar approach to innovation management among their contractors.

Standard practice here, innovation there

The open innovation approach of offers the opportunity for each contractor involved in the project to get a sense of how other companies work through what is submitted to the platform.

The platform is open to a wide range of innovation and the diversity of reveal what different contractors consider standard practice at a specific point in time. During our site visits, we discovered that innovations considered standard practice by some contractors, but unknown solutions for others.

The risk however is that some contractors may be less engaged with the platform if they feel that most of the submissions are familiar to their organisation. To address this any ongoing innovation programme should note that incremental innovations can only be submitted once so over time every contractor will submit ideas that represent a bigger innovative step for all involved. This highlights how vital it is for the innovation programme to engage all sites and maintain an active community of innovators across contractor employees who can use the platform to identify solutions to issues faced on their sites.

A potentially significant legacy of Crossrail's Innovation Programme for future large project (e.g. Thames Tideways and HS2) is that its database contains a range of ideas that are potentially relevant for other projects. Making this available to future mega-projects will reduce the time it takes to exhaust the future submission of standard practice and advance more quickly to more ambitious innovations.

GENERAL RECOMMENDATIONS

Setting up an innovation programme

The Crossrail innovation programme was set up without intended financial benefits as a key performance indicator, rather its objectives focused on number of innovations submitted to the platform and rates of diffusion of those innovations across sites. The innovation programme was only asked to calculate its financial benefits in retrospect, ao this explains why the programme did not have an established process to record ongoing benefits. The Crossrail programme shows that an innovation submission platform in an infrastructure project can be extremely successful, but to carefully evaluate the benefits accrued **key performance indicators must be defined at the start of the programme**. **Those KPIs should be defined in terms of both financial and intangible benefits** allowing the programme to develop processes and metrics to measure and monitor benefits over the life-cycle of the project.

Innovations big and small

Innovations submitted to the platform cover everything from modest improvement to existing processes to ground breaking new ways of working. This is normal and should be encouraged: no innovations should be thought too small as it is from those small changes replicated over and over

again that big differences in efficiency can arise. It is tempting to focus on the large-scale innovations that have big benefits. However, the largest innovations at Crossrail (such as the curved whalers at Whitechapel and the bespoke gantry crane at Custom House) are very site specific by nature and there is little scope for their adoption by other sites. Seemingly smaller innovations that entail more modest efficiency gains (e.g. pico projector or the Basestone software) have more potential for diffusion and thus could translate into significant efficiency gains, when shared across sites.

To create opportunities for small but reproducible innovations to enter the platform, it is probably better for the platform to be overly inclusive than too restrictive, but this should not disregard more ambitious innovations, which may be site specific or have a slower diffusion rate but should encouraged at the start of a project like Crossrail, and as it progresses, the focus should shift to innovations that have the potential to diffuse widely, even if they have seemingly smaller gains.

Encouraging an innovation culture

The innovation programme encourages an innovative culture among Crossrail and contractor employees. Its problem-solving approach to work is hard to capture and quantify but it is invaluable as individual employees are more likely to lookout for possibilities to optimize processes, that may have a negligible impact independently but when repeated over the whole workforce have large efficiency gain potential.

The current slowing of productivity in advanced economies is partially linked to the difficulty of increasing productivity in activities where machines cannot be substituted for people. This issue

is made more acute by the failure of firms to empower their employees to organise their work as efficiently as they can, resulting in a "doomed" top down prescription of how work is to be done. Indeed, the best people to find ways of working more efficiently are the individuals doing the job. The challenge then becomes two-fold: how can firms motivate the workforce to adopt a problem-solving approach, and maintain high standards of quality and security.

The setup of an innovation programme offers a partial answer to this question. Accepting that every aspect of the work can benefit from innovation changes the perception of processes from a rigidly prescribed manner of working, to a plastic entity that can be refined and improved, while checks and balance are installed to ensure workers safety and build quality (Adler, Heckscher, & Prusak, 2011). **An innovation culture empowers workers to suggest improvements to work processes**.

Pursuing a corporate entrepreneurship model

An innovation programme can be defined as a corporate entrepreneurship initiative (Wolcott & Lippitz, 2007), the purpose of which is often to support decentralized innovation within a large structure. The programme (and more specifically the innovation competition) allows participants to capture innovation in a network organisation composed of many contractors. This model is highly appropriate for Crossrail, but should not be expected to yield substantial returns, rather it can help to identify more radical innovations that receive time and support to come to fruition. Such a programme would be easier to legitimate and on an industry-wide scale, and it is to Crossrail's credit to have initiated such a competition which can significantly alter the culture of the industry and create a demand for innovation in the workforce.

Although the Crossrail Innovation Programme and competition started late, meaning that early stage innovations could not be fully developed and utilised to bring sufficient tangible or intangible returns, it is recommended that such competitions should be inititaed as early as possible in the life of a programme to create the most favourable context for success, but should be done with the expectation that there will be no returns for the programme. It is an important cultural shift for an industry to accept that innovation is risky and that most of the projects will ultimately fail (Farson & Keyes, 2002). It is also possible that great ideas largely produce returns outside of the project, being used by contractors in other contexts, when they have not or seldom been used on the original project. Yet, acknowledging and embracing risk allows the current project to reap other intangible benefits such as supporting an innovation culture, facilitating financial and technical support for employees to transform their ideas into innovations useful for the programme.

Conclusion

The innovation programme has helped foster innovation and collaboration at Crossrail. It helped maintain and grow the network of exchange across the different sites, creating opportunity for recombination of knowledge and novel solutions from different sources to disperse across sites, with the programme acted as a knowledge and resources broker.

From a financial point of view, a conservative estimate of the benefits accrued indicates that the programme more than paid for itself, before accounting for subsequent health and safety or intangible benefits.

The major intangible benefit of such a programme is to promote an innovation culture, which engages the workforce and fosters higher productivity, as well as a day-to-day problem-solving

orientation. The benefits associated with the Crossrail Innovation Programme are smaller than they may have been if initiated earlier, but the programme has achieved impressive results in the short time it has operated, benefits that have potential impact for the entire construction industry.

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