# Infrastructure Design for Evolvability: Theory and Methods

A Thesis submitted to the University of Manchester for the degree of
PhD in Business Administration
in the Faculty of Humanities

**2012**

**Guilherme Biesek**

**Faculty of Humanities**

## Contents

Word Count: 70539

# Other Lists

## List of Tables

**List of Figures**

## Abstract

The development of new infrastructure invariably requires massive capital investments, take many years to design and deliver, and are expected to operate for several decades. During delivery and operational lifetime, the functional requirements are likely to change. To make the assets economically adaptable to foreseeable changes, sizeable investments in design flexibility may be required upfront. Under uncertainty about the future and tight budgets, multi-stakeholder teams must trade-off additional investments in flexibility with more affordable investments in rigid designs at risk of costly adaptation. How to help project teams bridge their divergences and coalesce their views of the world into a project strategy is the core question at the heart of this research. After reviewing the limitations of current practice and theory in the management of capital projects, this study turns to real options reasoning. By definition, investments in design flexibility can be equated with buying options: if the future resolves favourably, the options can be exercised to adapt the design economically. To advance theory and practice on capital design for evolvability, this study combines case-based with experimental work. First, an exploratory study reveals that, despite using options thinking, project teams find real options mathematical models inadequate to support mundane design decisions. A subsequent study on design practices at Network Rail shows the difficulties of designing for evolvability become amplified with multiple stakeholders. With asymmetry in capabilities, knowledge, and power to influence decisions, multi-stakeholder teams systematically resort to a combination of informal options thinking and ‘money talks’ to resolve concept design. Tensions flare up whenever stakeholders demanding investments in design flexibility cannot fund them. These findings suggest that a formal procedure to design for evolvability can offer a superior approach at front-end strategizing. To test this proposition, this research develops an original proof-of-principle of a formal design for evolvability framing that cross-fertilizes literature on project risk management and real options theory with insights from the fieldwork. It also develops a two-group experiment – grounded on fine-grained empirical data from a real-world rail station project – to compare the performance of the experimental and control groups in terms of effectiveness, efficiency, and satisfaction. The results show that a formal design for evolvability framing can improve front-end strategizing. As project teams become more efficient, they have more time to effectively resolve the design for evolvability strategy. Importantly, teams are unlikely to reject attempts to formalize the decision-making process. The study also shows that a formal design for evolvability strategy can improve the accountability of decision-makers for investments in design flexibility. Final considerations discuss the generalizability and limitations of these insights, and future directions.

## Declaration

I hereby swear that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

## Copyright Statement

# Other Pages

## Dedication

I dedicate this work to my parents, Arquimino and Sueli, for the inspiration they have been to me. To my siblings, Tanara and Filipe, for being so understanding throughout these years I stayed away.

## Acknowledgement

I acknowledge and give thanks for the great support and direction to my principle supervisor, Prof. Nuno Gil. His meticulous feedback during our meetings and revision of manuscripts greatly improved my research skills and capacity of thinking. I would also like to thank my second supervisor, Dr. Eunice Maytorena Sanchez, for the great feedback and support in this research.

I thank Dr. Ermias Kebede for carefully reading my work and giving great feedback. I also thank Dr. Liwei Liu, Mr. Hussain Al-Arrayed, Ms. Sahar Karimi, and Mr. Daniel Hampson for their advice and help.

I give my thanks to Network Rail and all the practitioners who shared their time with me during interview and meetings. They were all very helpful and cooperative, especially Mr. Stephen Cooper and Mr. Peter Baxter.

Finally, I acknowledge the financial support from Manchester Business School and Project Management Institute.

# 1 Introduction

## 1.1 Problem Articulation

The design and development of new large-scale infrastructure assets is a fundamental project-based undertaking through which private and public organisations can create value. Physical infrastructure assets such as airports, railway lines, bridges, factories, hospitals, or power stations are main components (or systems) of critical and large socio-technical systems (or systems of systems) in transport, manufacturing, healthcare, and energy (Hughes, 1987). The development of new assets plays an important role in ensuring that existing socio-technical systems can respond to increasing demand for new services, evolution in usage patterns, and changes in technology. The development of physical infrastructure systems is also fundamental to ensure the broader socio-technical systems can cope with population increase, deterioration and obsolescence of existing assets, migration flows towards cities, and the globalization of supply chains (Gil, 2009a). Advocated by Keynesian economists as one 'road to recovery' in times of an economic downturn, capital investment in large-scale infrastructure projects contributes to the development of national economies by providing temporary and permanent employment, stimulating further investments, and promoting growth and development for local businesses. By the same token, the failure in delivering large-scale infrastructure projects effectively and efficiently can have enormous detrimental impact, both in the medium and in the long term, on the economy of whole nations, given the physical and economic scale of these projects (Flyvbjerg, Bruzelius, & Rothengatter, 2003).

A major challenge in new infrastructure development is the need to design and build new assets that can adapt economically to evolving requirements over long periods. Infrastructure assets may take many years to negotiate planning consent, design, and deliver. They are also invariably designed to operate for several decades – the construction of some railway stations in the UK, for instance, dates back to the middle of the $19^{th}$ century. However, during a prolonged project delivery and service lifetime the external environment will almost certainly evolve: new technology may emerge, user requirements and operating conditions may change, and new regulations may be introduced. These externalities can trigger developments in functional and operational requirements, which need to be accommodated through design changes. The cost of adaptation will then be a function of the flexibility built in the design of the asset.

Design definitions that are flexible to economically accommodate foreseeable changes in requirements in the future may need additional capital investment upfront to create modular architectures (Baldwin & Clark, 2000) or to safeguard integral architectures (Gil, 2007). From a life-cycle perspective, this additional capital investment to make the asset definition more flexible may pay off if the foreseeable uncertainties resolve favourably in the future. However, in situations where capital resources are scarce, requests for additional investment at the design definition phase cannot be taken as a given. By definition, large-scale infrastructure projects require large capital sums. Their design definition also takes many years to be negotiated amongst a large number of stakeholders. Any business case for an additional investment in a flexible design solution (which will only pay off if uncertainties resolve favourably in the future) will have to compete with other business cases for more immediate needs. Making a compelling case to invest in design flexibility at the project front-end can therefore be a challenge for public agencies operating under tight budgets and struggling to fund projects all deemed urgent. Scarcity of capital resources can also be a problem faced by private developers of infrastructure. Private companies operate under commercial pressures to achieve profits in relatively short timescales to meet the expectations of their shareholders.

Failure to make upfront investments in flexibility can nonetheless compromise the ability of the assets to cope economically with foreseeable change. Early design decision-making in new infrastructure development projects therefore requires balancing decisions to make long-term investments in design flexibility (in order to mitigate the downside risk of costly changes in the future) with investments in more rigid designs (at the downside risk that adaptation costs will be very high if uncertainties resolve favourably). Put differently, capital investments in flexibility at the front-end ensure that the project can deliver an effective outcome in that it has the capability to respond, with reasonable economic costs, to potential changes in the environment over its lifetime.

The problem of balancing upfront investments in design flexibility with decisions not to invest at risk but that reduce costs in the short-term is compounded by the fact that these decisions often need to be collectively negotiated. The number of project stakeholders invariably involved in negotiations to firm up the design definition is vast and includes project sponsors (the ultimate client such as a government or a corporation), the project client (typically an agent appointed by the project sponsor and often termed the project 'client' from a project suppliers' perspective); future operators, project suppliers; and other relevant stakeholders such as local communities, local authorities, and other public agencies. The claims of these stakeholders over the project definition may exhibit different levels of power, legitimacy and urgency (Gil & Tether, 2011), as well as conflicting priorities, and perceptions of risk (Gil, Miozzo, & Massini, 2012). Despite the autonomy of each stakeholder organisation, all organisations in the collective sense may share the ultimate project goal, a phenomenon observed not only in project-based undertakings but also in contemporaneous business ecosystems (Baldwin, 2012). Some stakeholders, however, will invariably advocate design solutions that maximize their individual short-term gains, as opposed to be driven to maximise the shared value that the project can create to the whole. Empirical studies for example suggest that often project promoters might endorse potential underperforming projects as long as they do not carry the risks themselves and are not accountable for performance failures (Flyvbjerg et al., 2003). Hence, early design decision-making in large-scale infrastructure projects is invariably the outcome of multilateral negotiations that require factoring in a number of stakeholder perspectives on the costs and risks of design flexibility. Each stakeholder's perspective will be shaped by different perceptions that foreseeable uncertainties will resolve favourably; the perceived costs of the design adaptation if uncertainties indeed resolve favourably; the appetite to take calculated up- and downside risks; affordability constraints and wherewithal to fund investments in flexibility; and the sense of entitlement to ask a different organisation to incur the capital costs of design flexibility.

Some stakeholders, particularly cash-strapped ones, may be reluctant to commit capital towards investments in flexibility that may take decades to pay off or that in some circumstances might not even pay off at all (Gil & Tether, 2011; Gil, 2007). Unless another party agrees to fund the costs of built-in flexibility at risk, these stakeholders may be willing to incur the downside risk of costly changes in the future at the expenses of creating an issue of intergenerational equity. A lack of incentives to invest in design flexibility can also arise whenever the organisations commissioned by the project sponsor to deliver and eventually build a project outcome have limited responsibility in regards to its future operational costs and the extent the asset will be able to cope with changes in the environment. For instance, some organisations may avoid including in their bids the costs of design flexibility to remain competitive (Laryea & Hughes, 2011; Taylor, Garvin, & Ford, 2012). The question of *who pays, when, why, and how much* is therefore central to front-end strategizing new infrastructure development projects as these projects invariably require different organisations to coalesce their strategic visions under conditions of uncertainty, urgency, and capital resource constraints into a concept that they can afford collectively and simultaneously ensures the desirable operational longevity of the asset.

## 1.2 Conceptual Context and Research Gap

Extant research in the management of capital projects and design has inadequately addressed the tensions arising from the need to trade off capital investments in design flexibility with other investments more likely to pay off in the short-term. The decision to invest in flexibility to mitigate the risk of costly changes unfolds when there is a scarcity of capital resources at *front-end strategizing* – the period upfront in the project development lifecycle when key stakeholders need to assess alternative design concepts and negotiate a concept to progress into the next project stage (Miller & Lessard, 2007; Morris, 1994).

Project teams have been exhorted to implement risk management practices to shield project delivery performance from the eventual occurrence of foreseeable events such as changes in design requirements and in relevant design standards, technological developments, and stakeholders' opposition to the project (PMI, 2004). These recommendations emphasise the value of change controls and governance structures to ensure that the business case underpinning each change request is assessed before a change can be instructed to project teams. This way changes that add value can be endorsed to ensure the effectiveness of the project outcome. Changes that fail to deliver value can be rejected to protect project delivery efficiency. These recommendations, however, fail to acknowledge how the quality of the design definition, integral vs. modular, will affect the costs to implement late changes. They also do not ask whether it would be better to allow the design to proceed with parts unresolved until more information would become available. This is the so-called design postponement principle long known in new development processes. Klein and Meckling (1957) for example argue that the efficient management of a new development process under uncertainty and ambiguity such as a new aircraft should seek to narrow down the design choices as development proceeds and more information becomes available. In contrast, conventional project management recommendations tend to fall under instructionist approaches that emphasize the pre-specification of stages to identify, estimate and respond to risk (Pich, Loch, & Meyer, 2002).

In the world of capital projects, several scholars have also observed the need for management to adopt an adaptive approach to ensure projects add value to their sponsors (Gil, Tommelein, Schruben 2006; Shenhar and Dvir 2007). This means that managers should freeze the project definition as late as possible, accepting that the project as a whole is not just a collection of activities. Rather, projects unfold under conditions of uncertainty (difficult to predict future states of the world) and ambiguity (a more extreme start of the uncertainty that makes it difficult even understand what the problem is, Pich et al. 2002) and project organisations need to adjust the project goals as the uncertainties in the environment get resolved over time. Empirically, the idea of design postponement has been formally applied to megaprojects. Gil and Tether (2012)'s empirical study on Heathrow's airport Terminal 5 project for example discusses how the airport owner and operator institutionalised the notion of 'last responsible moment' to delay design commitments and build in flexibility given foreseeable evolution in the requirements of the future airlines moving into the terminal and in airport technology and procedures over the many years needed to deliver the terminal.

Kahkonen (2006) adds to that arguing that there is a fundamental need to improve risk management practices, especially regarding risk concepts and risk perceptions as well as in terms of providing a more holistic approach that attends to the needs of the different stakeholders. As Lenfle and Loch (2010) put it for the case of product development projects, practices that overemphasise the application of risk management to protect efficiency are bound to overlook opportunities to create value through investments in flexibility and novelty that will make the project outcome more effective. The difficulties in reconciling calls for investing in flexible solutions at risk the investments will not pay off with pressure to reduce capital costs under conditions of uncertainty has motivated calls for building options logic into project front-end strategizing (Gil, 2007; Miller & Lessard, 2007).

Options logic posits that strategy can be used to gain advantage under conditions of uncertainty (Black & Scholes, 1973; Merton, 1973). The aim of option-pricing theory is to provide analytical methods to guide the investor into making strategic investments under uncertainty that will enable investors benefiting from upside scenarios while limiting losses on the downside, i.e., options logic introduces an asymmetry in the probability of distributions of payoffs (Merton, 1998). Real options theory draws from analytical studies on financial options, and explores their applicability, not on investment decisions in pure financial assets, but to decisions to invest in physical assets (Amram & Kulatilaka, 1999; Smit & Trigeorgis, 2004; Trigeorgis, 1996). Studies in real options have predominantly applied analytical methods to price capital project investments with built-in options (e.g., Lee, 2007; Smit & Trigeorgis, 2004; Zhao et al., 2004).

Despite the advances of real options science since the mid-1980s, when options pricing models began to be used to value investments in real assets, and despite the current availability of various analytical methods to help assess capital investments, the uptake of the real options approach in capital investment practice has been slow. In 2002, for example, Ryan and Ryan (2002) indicated that 88.6% of Fortune 1,000 companies had rarely or never used real options. Five years later the figures in regards to adoption had hardly changed, when Block (2007) reported that only 14.3% of Fortune 1,000 companies were using real options. The slow rate of adoption of real options theory in practice is in marked contrast with Copeland and Antikarov (2001)'s predictions, which suggested that the real options valuations would take off and dominate strategic investment decisions within a few years. Admittedly, examples of successful adoption of real options have been found. However, they tend to be observed in industries where large investments with uncertain returns need to be made (Triantis & Borison, 2000). Evidence suggests that the use of real options methods have been limited to sophisticated analysis of capital investment decisions to acquire technology, energy systems, and utility companies (Block, 2007).

In contrast, empirical studies unsurprisingly suggest that very seldom real options analytical methods are used to inform more mundane design decisions. In these circumstances, the payoff of having an option might be only limited, which can restrict the amount of time and effort that companies can dedicate to the decision-making. Also, the option itself might require a large upfront investment relatively to both the potential payoff it can provide (if uncertainties resolve favourably) or to the downside risks it can reduce. Therefore, the use of sophisticated analytical real options tools for mundane design decisions might understandably represent overkill given that applications of real options are seldom trivial. Rather, the use of real options methods can turn out challenging, when not overwhelming, due to a conflation of reasons notably difficulties in making reliable assumptions, in ensuring that the analytical models stay tractable, and in developing simple but accurate analytical representations of real-world problems (Bowman & Moskowitz, 2001; Kalligeros, 2006; Lander & Pinches, 1998).

Due to the reluctance among practitioners in using analytical real options pricing models, an alternative research stream has gained traction in the areas of assessing technology and R&D investments: real options reasoning (MacMillan, Putten, McGrath, & Thompson, 2006; McGrath & MacMillan, 2000; McGrath, 1997). This approach preserves the logic of the real options theory to assess the value of flexible solutions, but sidesteps the difficulties of quantitative modelling. Real options reasoning uses options logic to develop qualitative methods that can support decision-making under uncertainty. McGrath and MacMillan (2000), for instance, develop a method that translates the parameters derived from options pricing into a series of qualitative statements, and then asks managers to specify their level of agreement with each statement before prioritizing technological options and allocating resources. Other authors (MacMillan et al., 2006) have further real options reasoning applications into methods that aim to support longitudinal decision-making processes under uncertainty, providing mechanisms through which decision-makers can ensure the periodic validation of assumptions and update of rationales. Similarly, Angelou and Economides (2008) have developed a decision-making support framework that combines real options analysis and analytical hierarchy process (AHP) to help people collectively prioritize capital investment in a portfolio of information and communication technology (ICT) projects.

Some evidence also suggests rudimentary use of real options reasoning in capital infrastructure development projects. In the UK, for example, a health trust has spelled out in the tender documents that the consortiums bidding for developing and operating new hospitals through a private finance initiative (PFI) should 'future-proof'[1] the design, factoring in the costs for building pre-specified flexibilities upfront and for exercising them in the future if need be (Lee, 2007). Likewise, options logic has been informally used to support the write-up of the design brief that safeguarded the economical adaptation of the largely integral design of Heathrow airport's Terminal 5 to future changes in operational requirements (Gil,

[1] Future-proof is a practitioners' jargon referring to designs with provisions built-in to mitigate the risk of costly adaptation to foreseeable changes in requirements in the future.

2007). Extraordinarily, however, empirical studies suggest that capital projects teams rarely – if at all – receive training on options logic (Ford, Lander, & Voyer, 2002; Gil, 2007; Kalligeros, 2006). Admittedly, the costs of investments in sophisticated real options pricing models to assess relatively mundane design decisions at the project front-end may be disproportionate to the potential benefits that these investments can generate. Nevertheless, an excessive reliance on informality to inform decision making in design flexibility makes decision outcomes vulnerable to short-term thinking, reduces accountability, and makes the whole decision-making process also more vulnerable to the self interest of politically strong parties.

Another concern with leaving important capital design decisions to be made on purely informal terms is the vulnerabilities of intuitive decision-making. Lovallo and Kahneman (2003) argues that decision-making in the context of capital investment based purely on people's intuitive perceptions about the environment – what they call the *inside view* – has serious pitfalls due to the cognitive biases and organizational pressures. Executives and entrepreneurs, the authors argue, if left to make pure intuitive-based decisions, are susceptible to overestimate benefits and underestimate costs. They may do so due to natural inclination to be optimistic, the pursuit of their own ambitions, or encouraged by company policies that reward optimistic assessments and may punish pessimistic opinions. A more grounded outside view exhorts decision-makers to adopt formal methods that can help to play their assessments against analogous cases and challenge their assumptions and their natural way of thinking. A formal method can help understand the sources of over optimism, bring alternative perspectives and obtain a clearer view of the future, making their forecasts more objective and reliable.

Taken together, the existing gap in the provision of suitable and formal methods to support mundane design decision-making at the project front-end strategizing creates a research opportunity. On the one hand, sophisticated real options analytical models fit poorly with the nature of mundane early design decisions. On the other hand, intuitive assessments of future-proof decisions do not offer an alternative because they are vulnerable to misjudgement and lack of accountability.

This gap provides the motivation for this doctoral research. The ultimate purpose is to develop a formal framework to support design decision-making at project front-end strategizing drawing from real options reasoning. The underlying hypothesis is that adding a degree of formalisation to early design decision-making can improve the quality of the front-end strategizing process and of its outputs in capital projects. This framing is called *design for evolvability* – evolvability is the ability of a natural or artificial system to change its design over time (Beesemyer, Ross, Fulcoly, & Rhodes, 2011). The idea of designing a system to evolve is not entirely new. Drawing evolutionary studies in biological systems that seek to observe and explain how organisms naturally changed across generations, Gagliardi et al. (1996) discuss the mechanisms that dictate how man-made systems can technologically evolve over time. They develop and test prototypes of evolvable systems in the area of real-time computing before broad-scale or commercial development of these computer artefacts. Similarly, Beesemyer et al. (2011) contrast biological and technological studies to yield insights on prescriptive design principles for designing for evolvability. Both studies theoretically postulate principles or mechanisms that man-made commercial product designs such as the design of a car platform need to attend to in order to evolve over time as technology and user needs change with reasonable economical costs. The purpose of design for evolvability in commercial product development is therefore to ensure the design can be reused from one new product development project into the next. These principles include: the modularization of a system to allow easy replacement of small parts without comprising the whole system, the selection of crucial modules that should be immune to changes to reduce costs of adaptation of the system, the definition of common interfaces to allow compatibility among different modules (Beesemyer et al., 2011; Gagliardi et al., 1996).

The purpose of design for evolvability in the world of infrastructure development however is different. In this world, project sponsors typically have fewer opportunities to exploit an existing design over time, which limits design longevity. Of course there are exceptions. Engineering consultants often design base cases of by-pass viaducts that can be reused from one highway project into the next.

Another exception is the case of Intel's Copy Exactly policy, which instructs the capital project teams to reuse proven designs of new high-tech semiconductor fabrication facilities (fabs) from one project into the next, provided that the manufacturing technology that the new fab will host has not changed dramatically in relation to that hosted by the old fab (Terwiesch & Xu, 2004). Empirical studies have suggested however that the reuse of infrastructure designs is not trivial due to differences in local requirements from one project to the next (Gil & Beckman, 2007) and due to the intermittent nature with which sponsors of capital projects initiate new capital investments. For example, the time lag between the conclusion of Heathrow's airport Terminal 4 and the start of Terminal 4 was around 20 years (Gil & Tether, 2011). This intermittency has also been observed in the development of new hospitals in the UK. Although such developments may happen almost continuously at national scale, they represent an intermittent activity at the level of the health care trusts that ultimately set the local requirements (Barlow & Köberle-Gaiser, 2008).

Design for evolvability in the world of new infrastructure development projects and capital projects more generally is therefore a notion that aims to account for the need to develop designs that enable the physical asset to cope economically with the occurrence of foreseeable changes in requirements during project delivery and later over the asset's operating life-time. The conceptualization and validation of novel framing to design for evolvability at the front-end strategizing of a capital project is the core purpose of this research. The approach is not new in the world of technology and R&D investment (MacMillan et al., 2006; McGrath & MacMillan, 2000). To the best of my knowledge, however, no previous research has developed a formal framing that seeks to combine established practice in the management of capital projects with real options reasoning and validated the framing with experimental research. Cardin et al. (2012) recent experimental study is closer to this research, but has focused on evaluating the effects of educational training to raise awareness about the value of investments in design flexibility under conditions of uncertainty when undertaking net present value analysis of a capital investment. Unlike this study, however, Cardin et al. (2012) experimental study is grounded on fairly simple front-end strategizing processes that involve but one key decision-maker. In contrast, this empirical study of front-end strategizing practices at Network Rail revealed front-end strategizing is often intertwined with challenging multilateral negotiations between equally legitimate and powerful stakeholders that bring different and often conflicting needs to the project front-end. This doctoral research therefore aims to explore the value added of design for evolvability under conditions of uncertainty and plurality of stakeholders. Importantly, this study also sought to develop theory on capital design for evolvability that factors in the affordability constraints almost inherent to front-end strategizing capital projects. Albeit seldom acknowledged in real options literature, the question of who pays the costs of the options must inform any effort to capital design for evolvability that unfolds in a multi-stakeholder environment.

## 1.3 Research Purpose, Objectives and Research Questions

The main purpose of this research is to conceptualise and validate a novel formal framing to support early design decision-making at the front-end strategizing of new infrastructure development (capital) projects. Specifically, the research aims to address the question:

> How can physical infrastructure assets be best designed to ensure they can adapt and evolve economically to cope with foreseeable changes in design requirements over project delivery and operational life?

To achieve this purpose, this research will first empirically investigate the nature of early design decision-making in capital projects involving a varying number of relevant stakeholders, and particularly the extent to which project teams adopt options logic is adopted to support decision-making. The motivation for this empirical work is driven by three questions:

> R1: To what extent capital project teams may intuitively use options thinking to support early design decisions under conditions of uncertainty?

R2: To what extent is it feasible to assume capital project teams may be willing to adopt real options analytical models at front-end strategizing capital projects?

R3: What challenges do capital project teams, that bring together otherwise disparate organisations, face when making early design decisions under conditions of uncertainty?

Based on the cross-fertilization of the empirical findings with existing research on options logic and the management of capital projects, this doctoral research will develop theory on design for evolvability and will validate the usability of an original proof-of-principle of a formal method to design for evolvability. The development of the proof-of-principle aims to: (a) verify the feasibility of using a formal method to help decision-makers incorporate options logic – both in terms of lexicon and structured procedures – to support design decision-making at front-end strategizing capital projects; and (b) investigate as to whether a formal design for evolvability framing can improve the quality of the front-end strategizing process and its outcomes, particularly when multiple stakeholders have to coalesce their conflicting interests and positions into a unified vision for the design concept of an infrastructure asset under conditions of uncertainty. Through a two-group controlled experiment that simulates the front-end strategizing process of a real-world capital project, this doctoral research seeks to validate the core proposition that a formal design for evolvability framing adds value at front-end strategizing along three core dimensions: effectiveness, efficiency, and satisfaction.

### 1.4 Dissertation Structure

This dissertation consists of eight chapters structured as follows. Chapter 1 introduces the problem of trying to conceptualise large-scale infrastructure assets that can accommodate foreseeable changes in requirements at reasonable economic costs in the future. This section discusses the motivation for this research and articulates an opportunity to advance existing research. The section concludes by presenting the purpose and objectives of this doctoral research, and the research questions embedded in the study. The subsequent chapter presents an in-depth review on the relevant literatures on the management of risk in capital projects and real options. The review discusses the motivation for combining two research streams that have remained largely separated. Chapter 3 describes the research methodology adopted to develop and validate a novel framing to support design decision-making at capital project front-end strategizing. It explains why this research combines field-based research (exploratory and in-depth case studies) with lab-based experimental research. The subsequent chapters present the empirical findings of an exploratory case study on the development of the Upton-upon-Severn Viaduct, a £3.5M project sponsored by a local authority to replace a structurally deficient viaduct (Chapter 4) and of front-end strategizing practices at Network Rail, the owner of UK's rail infrastructure (Chapter 5). These two chapters discuss how the real options analytical tools might be excessively complex for supporting early mundane design decisions at the project front-end. The findings also reveal that despite the systematic use of options thinking in practice, this use remains largely intuitive. Chapter 6 then describes the effort to develop a novel framing to formally and systematically support front-end strategizing of new infrastructure development (capital) projects. The subsequent chapter reports the process of validating this framing using a two-group controlled experiment grounded on a real-world capital project. Finally, Chapter 8 discusses the conclusions and contributions to knowledge and practice of this doctoral study. It also discusses the limitation of the research and points out future research opportunities.

# 2 Literature Review

This doctoral research combines two main literature streams that have remained largely disparate in prior work: literature on the management of capital projects and literature on real options. The motivation for combining these two literatures was the ultimate purpose of the research – developing a new conceptual framing to improve the quality of project front-end strategizing, a practice and a theoretical concept at the heart of the management of capital projects arena (Morris, 1994, 2011). The literature on the management of major projects reviewed in this chapter offered a good understanding of the importance of investing early on in front-end strategizing in order to reduce unproductive design iterations over the project delivery stage (Gil, Tommelein, & Schruben, 2006; Thomke & Fujimoto, 2000). This literature also elucidated the fuzzy nature of front-end strategizing which means project teams are asked to develop narratives and make decisions with major implications to the subsequent project phases under high uncertainty about the future states of the world (Morris, 2011). Surprisingly, however, not much in-depth conceptual work has been undertaken that combines this literature with literature on real options, a research stream that offers theory and a raft of methodologies and frameworks useful to help individuals make strategic investment decisions under uncertainty (Neufville & Scholtes, 2011; Trigeorgis, 1996). Admittedly, the potential for intersecting the two literature streams has been uncovered in prior works (Ford et al., 2002; Zhao et al., 2004). Wang and Neufville (2005) coined the notion of 'options in projects' in contrast to the mainstream strategic investment literature on 'options on projects'. The latter research stream is well established in the world of finance. It pertains to the use of real options theory to inform capital investment decisions at a macro level of analysis. A typical line of investigation in this research stream may explore the strategic value of an airport considering its potential to expand in the future (Trigeorgis & Smit, 2009). In contrast, the work on options *in* projects is still in its infancy. It focuses on the problem of assessing the value of building particular options in the design definition of a new capital project. The definition of the concept design is inherent in the nature of the front-end strategizing a new capital investment (Gil, 2007; Guma, Pearson, Wittels, Neufville, & Geltner, 2009; Neufville & Scholtes, 2011).

By combining literatures on the management of capital projects and real options, this research creates a conceptual context more amenable to uncover new methodologies and produce theory that can be of real value to decision-makers confronting front-end strategizing problems, and having to address the perennial problem of balancing efficiency and effectiveness in major projects (Gil & Tether, 2011; Miller & Lessard, 2007). Unarguably, project front-end strategizing needs to offer more than what is currently available in the conventional project risk management techniques. The available techniques tend to simply shield the project performance from disruptive events – foreseeable upfront to a certain degree – that may occur during the project delivery stage. Project front-end strategizing also needs to find ways to cope with disruptive changes, some of which could be hard to predict upfront in ways that are reasonable in socio-economic terms. This is where this research hypothesizes that an intersection of real options theory with theory on the management of capital projects can produce a conceptual environment fruitful to develop a systematic way to formally incorporate an assessment of foreseeable uncertainties at project front-end strategizing. Previous researches have applied real options to inform a company's internal strategic decisions to invest in new product development projects (Ford & Sobek, 2005; Rese & Baier, 2007). This research claims that an intersection of real options with capital projects needs to attend to the multiple stakeholder nature of front-end strategizing (Hult, Craighead, & Ketchen Jr., 2010; Taylor et al., 2012) and how the process needs to factor in the heterogeneous needs and capabilities of these multiple stakeholders and look beyond the needs of the suppliers involved in the design and implementation phases. These claims are aligned with Gil et al. (2012) study, which explores the challenge of negotiating multilateral agreements between stakeholders in order to adopt innovations in capital projects developments.

This literature review is organised as follows. It starts with a review of literature on the management of projects particularly around front-end strategizing and risk management practices. This review is then followed by an analysis of the relevance of real options theory to capital project front-end strategizing, looking both to quantitative and qualitative approach in real options reasoning and the extent these approaches have been integrated with capital project literature to bring options thinking in front-end strategizing.

## 2.1 Capital Management of Projects: Integrating Risk Management and Design Flexibility at Front-End strategizing

The practice of project risk management has long been adopted in capital project development as a way to identify potential risks and the likelihood of their occurrence, measure their implications if they indeed occur, and take appropriate countermeasures to reduce or mitigate those eventual impacts (Chapman & Ward, 2003). This execution-oriented approach to risk management is characteristic of established project management practices as documented in the Project Management Body of Knowledge (PMBOK®) guide that by and large offer a sequential number of steps that project teams need to adopt in order to cope with managerial problems (PMI, 2004). Some authors (Shenhar & Dvir, 2007, Lenfle & Loch, 2010; Morris, 2011;) have argued, however, that execution-orientated approaches are largely inadequate to cope with the risks to project execution that originate from developing a project in a constantly changing environment. In fairness, literature on risk management, particularly at the conceptual level, has evolved since seminal works in order to develop practices more robust to the occurrence of foreseeable and unforeseeable changes during project execution (Alessandri, Ford, Lander, Leggio, & Taylor, 2004; Winch & Maytorena, 2011). In spite of that, the approaches documented in the PMBOK® guide still lies at the heart of capital project management practices. The following sections discuss the limitations of the current approaches especially in the development of new infrastructure capital projects. This review allows identifying opportunities in the literature to develop project management practices that can adopt a more holistic approach.

### 2.1.1 Risk Management

The Project Management Institute (PMI) defines project management in the PMBOK® guide as “the application of knowledge, skills, tools, and techniques to project activities to meet project requirements” (PMI, 2004, p37). This guide provides project managers with a fundamental reference on how to apply and integrate sequential processes to initiate, plan, execute, monitor and control, and close the project. In recent work, Meredith and Mantel (2010, p22) adopt a similar execution-oriented definition to the practice of project management: “the means, techniques, and concepts used to run a project and achieve its objective”. Both definitions of project management relate to what Pich et al. (2002) describe as the ‘instructionist’ approach. In this approach, both practitioners and scholars tend to emphasize the pre-specification of tasks and trigger actions based on signals in order to ensure that the development of projects follows an ideal and more profitable path (ibid).

Risk management practices, in particular, have long been at the core of established project management practices. Broadly defined, risk is the possibility that different events, their consequences, and interactions may turn out differently than expected (Miller & Lessard, 2001). Although risk and uncertainty are often used interchangeably, prior work has differentiated the two concepts (Knight, 1921; March & Simon, 1958). Uncertainty tends to express a condition of not being sure about the occurrence of some event to the extent it is hard to pin down any likelihood of occurrence and when it may occur, if it occurs. Risk expresses a condition of uncertainty for which available knowledge is enough to attempt to quantify the likelihood and the impact (March & Simon, 1958). This definition is in agreement with PMI (2004) working definition for risk: an uncertain event that, if it occurs, has an impact (positive or negative) on the project outcome (PMI, 2004).

Different types of risks can be identified that can affect the delivery of large engineering projects. For example, evolution in demand forecasts can cause the need to change the design requirements. The adoption of new technologies that may not yet have been fully tested can turn out to be more challenging than initially anticipated. Changes in laws, regulations, and norms can have implications to design decision and work practices in design and construction. Social groups can voice opposition to a particular project and give rise to challenging situations that need to be managed during project delivery. Miller and Lessard (2007) propose one typology that categorises all these risks in the function of their causes as: (1) market-related risks (due to conditions of uncertainty in demand, financial activities, or supply inputs); (2) completion risks (due to engineering difficulties faced during the project design and building, and even operations); and (3) institutional risks (due to regulatory, social, and governmental issues that can be relevant for the project). Another typology categorises risks according to the organisational level (Merna & Al-Thani, 2005): some risks are corporate-related such as those stemming from political, financial and legal changes; some risks are related to strategic business decisions such as economic, natural and market risks; and some risks are related to the project execution phase such as technical, health and safety, operational and quality risks. This large universe of risks makes it essential to unbundle foreseeable risks at the project front-end, analyse the risks separately, and put together early on adequate mitigation and contingency plans. This is exactly the aim of risk management practices.

Risk management practice consists of systematically identifying sources of risks, assessing their interactions and implications, documenting the risks into risk registers, and taking the appropriate actions to mitigate the negative impacts stemming from their eventual occurrence (Chapman & Ward, 2003). Risk management practice aims both to reduce the adverse outcomes, i.e., downside risks, as well as to exploit opportunities in favourable scenarios, i.e., upside risks (Hillson & Simon, 2007). There are several ways to represent risk management practices. Kahkonen (2006) asserts that conventional representations tend to describe procedures and routines typically observed in capital project settings such as risk identification, risk estimation and mitigation, and contingency planning – approaches that by and large tend to fall under the instructionist category in Pich et al. (2002)'s classification of project management approaches.

The PMBOK® guide defines the practice of project risk management as "the processes concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project" (PMI, 2004, p237). This body of knowledge establishes a number of phases that project managers need to go through to maximize opportunities (increase the probability of positive outcomes) and minimize threats (decrease the probability of negative outcomes). The main phases in their recommended risk management practice are: documenting and characterizing the risks affecting the project; assessing risks usually through the allocation of a risk probability and a risk impact, which indicates opportunities that should be pursued and threats that should be mitigated (typically through the probability and impact matrix); defining actions (e.g. contingency plans) to respond to risk events; and repeating the cycle of identify, quantify and respond to risk over the project life cycle in order to account for changes that might have proved previous expectations wrong.

The implementation of these risk management practices might be satisfactory and arguably cost-effective for a number of capital projects. However, some authors argue that these practices are generally inadequate to cope with the nature of the risks involved in projects which are characterized by ambiguity of future scenarios and complexity decision-making processes (Kahkonen, 2006; Pich et al., 2002;). Projects must constantly adapt to new specifications and planning should not be rigid, but able to be reshaped as the project moves forward (Shenhar & Dvir, 2007). Furthermore, Merna and Al-Thani (2005) state that the emphasis on quantification in risk management procedures, such as quantitative risk analysis, might prevent non-conventional risks from being recognised in projects. This is precisely the case of new infrastructure development projects. To cope with foreseeable risks in infrastructure developments, project teams want to actively strategize their activities within the project to influence outcomes, for example, by sketching-out the components of risks, defining the managerial strategies to cope with them, and outlining the processes that will guide the management of risks (Miller & Lessard, 2000). Failure to diligently manage project risks at the front-end can create opportunities for the emergence of situations difficult and costly to resolve later in the project life-cycle especially as the investment sunk into the project and the scale of the financial commitments increases (ibid).

The term front-end strategizing originated in studies in the field of new product development. The fuzzy front-end corresponds to the activities at the initial stages of a commercial product development project, when teams have limited information about the viability of new technologies and the evolution of market needs, but need nonetheless to start making important strategic decisions that are going to strongly impact the project (Smith & Reinertsen, 1998). Thompke and Fujimoto (2000) adopted the term *front-loading*, as it “loads” the “front” of the process with activities that promote a better understanding of requirements before the detailed design and development of a new product. Front-end strategizing in capital projects – which typically involves project definition, concept selection, and planning – exhorts developers to invest time and effort at the start of a capital project to think through alternative scenarios that might affect the design requirements (Morris, 1994). Since problem resolution becomes by and large more expensive and time-consuming as the project progresses from the early stages into detailed design and execution, and more commitments on the project definition are made, front-end strategizing aims to move the problem identification and solution backward in time in order to improve development performance and reduce costs (Thomke & Fujimoto, 2000). For front-end strategizing to be effective, project teams need to combine prescriptive activities such as defining the scope and tasks, risk management, and planning contingent actions and budgets to counter impacts (Cleland & King, 1983; Cooper & Chapman, 1987), with other activities such as scenario planning, talking to end-users/communities, and discussing the political/economic environment.

The risk management practices at the project front-end can be particularly problematic to implement when multiple stakeholders are involved. Because of the variability in the subjective perceptions of risks across the relevant project stakeholders, some risks can be difficult if not impossible to quantify (Merna & Al-Thani, 2005). More importantly, the benefits of adopting counter measures to cope with perceived risks, and consequently the perceived value that the measures may bring to a project, can vary significantly across actors. In such circumstances, setting a specific plan on how to achieve the expected benefits is not as problematic as attempting to define what these benefits are in the first place. To allow an adequate management of risks, Dallas (2006) argues that project teams should seek to reconcile these perspectives of different stakeholders and find the right balance between their conflicting interests. Some authors (Chapman & Ward, 2003; Dallas, 2006; Merna & Al-Thani, 2005) assert that this should be done by aligning the risk management with value management practices.

Value management is about defining what is needed in a project in order to deliver the expected benefits both in terms of strategic needs of the business and in terms of client and users expectations. Value management practices aim to ensure that the benefits can be achieved effectively, economically and efficiently, using the minimum resources (Dallas, 2006). The alignment of risk management with value management practices can allow project teams to minimise the negative impacts of risks and to maximise the value of the project. Project teams are able to do so by ensuring that the benefits of a project, at the price the project team can afford, are clearly defined, understood and communicated to those who will deliver it (Dallas, 2006; Morris, 2011). If the project benefits can be clearly defined, project teams will be in a better position to (1) compare the project benefits with the costs of project delivery, (2) assess whether the project investment represents good value for money, and (3) define whether the benefits can be achieved once affordability constraints have been considered (Dallas, 2006). The alignment of value management practices with risk management practices ensures that the ultimate benefits that the project can generate for a community of stakeholders, rather than the benefits stemming from the project for a particular stakeholder, can be accomplished. Merna and Al-Thani (2005) argue that the mapping between risk management practices and value management practices should be initiated as early as possible in the project life cycle, but this is not trivial. Managing risks very early in the project is inherently difficult as little information is available; managing risks when all information is available might be simply too late (Merna & Al-Thani, 2005). This dilemma is also explored by Williams, Samset and Sunnevag (2009) when investigating the development of capital projects. They recognise the challenges of making decisions that are likely to significantly impact the success or failure of the project, but need to be taken with scant information. The restricted knowledge about the project is the only information available at the early stages of project, when epistemic uncertainty is at its highest, but when the design concept needs to be chosen.

### 2.1.2 Beyond risk management

The analysis of the history of project management and of some spectacular failures of major capital projects has led a number of scholars to argue that the excessive emphasis by the project management literature, both scholarly and practitioner-oriented, on a sequential and execution-oriented approach has been inadequate (Flyvbjerg et al., 2003; Lenfle & Loch, 2010; Morris, 2011). The emergence of a less prescriptive approach to the management of projects can be traced to Morris and Hough's (1987) seminal analysis of major projects. In their book, the authors show evidence that the typical sources of project failures are rarely associated with technical and managerial difficulties experienced by the project team who was awarded the project in accomplishing efficiently the goals set at the onset. They also argue that project failure cannot be exclusively attributed to the difficulties of the project teams in mastering the numerous tools and techniques that are available in practice to manage risks and organise the network of project activities such as the Planning and Evaluation Review Technique (PERT) and the Critical Path Method (CPM), or tools to structure the work that needs to be accomplished and the project organisation such as the Work Breakdown Structures (WBS) and contingency planning. Rather, in their seminal work, Morris and Hough argued that major project failures are more likely to be caused by other factors – outside the scope of the more traditional project management practices – such as poor project definition, absence of a project owner, political instability, lack of top management support, and changes in project sponsorship.

This critique to the more prescriptive project management literature has gained momentum since the early critiques. In a more recent study, Flyvbjerg et al. (2003) for example argue that there are two main reasons for infrastructure project failures. One reason is the inadequate management of risks, which strongly relies on forecasts that inappropriately assume that things will resolve according to plan. Another reason is the lack of accountability in the decision-making process, a point that is aligned with critiques to the excessive reliance on the prescriptive approach made first by Morris (1994) and later by Pich et al. (2002). This body of literature has continued to grow. Gil and Beckman (2009) for example discuss the role of the client in the management of capital projects, and how clients are a major source of late change. Whilst some late changes are very disruptive and penalise process efficiency, these changes can be underpinned by compelling business cases and need to be instructed to the project teams in order to ensure the project delivers outputs that meet the customer needs. Recent empirical work on the management of the Heathrow airport expansions, the Terminal 5 projects, is particularly insightful on the need to balance efficiency and effectiveness in major projects (Gil & Tether, 2011).

Other literature also notes some projects are designed to fail due to the poor management of ex ante project appraisals (Flyvbjerg, 2009). Flyvbjerg et al. (2003) show numerous examples of projects where the actual final costs were much higher than the initial cost estimates tabled at front-end strategizing. These failures originated from the difficulties in predicting at the project front-end how things will get resolved in the future combined with the poor (and sometimes even deceptive) project appraisals and the lack of involvement of relevant stakeholders (particularly the operational people). Along the same lines, Laryea and Hughes (2011) show that in several occasions firms tend to deliberately exclude risks from contracts to enhance competitiveness. They argue that the deceptive contract formulation can guarantee a particular firm ‘getting a foot in the door’, but it can also contribute to project failures, and it certainly makes the contingency approach underpinning prescriptive risk models unsustainable in practice. Clearly, from an efficiency perspective, these projects were designed to fail because the initial targets were unrealistically low.

As critiques to the prescriptive project management literature gained momentum, scholars rarely disagree that the traditional project management practices particularly around risk management are necessary and valuable, but need to be complemented by other practices. Morris (1994) was pioneer in arguing for a more holistic approach, making an important distinction between the practice of project management and the broader field of the management of projects. In his work, Morris sustains that the latter framing provides a more holistic view than the traditional approach, which is too limited to deliver a capital project successfully. Managing projects is more than focusing on managing project activities that were set up in an activity-based network once the requirements for the project had been defined. However, Morris work is shy of assuming that requirements in a capital project are going to evolve as the project unfolds. The main argument underlying the management of projects approach is a rather prescriptive one and pivots around the need to ensure that the project requirements are adequately defined at the early stages. If more time is invested in 'front-end strategizing', fewer risks will have to be fended off by the project team tasked to protect project efficiency.

Influenced by studies on more dynamic environments related to commercial product development projects, Lenfle and Loch (2010) go further than Morris in calls to build flexibility in the project management approach. They explicitly argue that the stage-gate approach at the core of the traditional project management discipline can prevent the emergence of innovative and flexible solutions for the project outcome. The recent empirical studies on airport capital developments extend this argument, and show that risk management practice and design flexibility must be understood as complements in the management of capital projects (Gil & Tether, 2011). Capital projects cannot get away with risk management practices around activity-based planning, contingency planning, identification of risk probabilities and impacts, governance, and change control. It would be delusional to think that investments in prescriptive risk management practices would eliminate the need to cope with late changes, some of which may be foreseeable upfront (but hard to pinpoint as to whether they will effectively happen or not, and if they happen, when) and some of which may be even unforeseeable upfront. To cope economically with the need to accommodate late change to ensure the capital project delivers an effective outcome that meets the needs of the customers, flexibility in the design becomes paramount (Gil & Tether, 2011). Investment in design flexibility at project front-end strategizing cannot however be taken for granted. Rather, Gil and Tether elucidate how these investments need to be negotiated and bargained between multiple stakeholders and how they are particularly difficult to 'sell' at front-end strategizing if key stakeholders involved at this stage struggle to cooperate with one another. Cooperation between stakeholders is important so project teams can develop a shared understanding of the foreseeable uncertainties facing the project over its delivery and operational life-cycle, and collectively build compelling business cases calling for additional investments in design flexibility upfront (Gil & Tether, 2011). If the project sponsors endorse calls for investments in design flexibility at front-end strategizing, the project can progress into the execution phase in a significantly better footing than if the outcome from front-end strategizing is a rigid concept design that is costly to change.

Whilst prior work has not explicitly acknowledged the need to balance conventional prescriptive management practices with investments in flexibility, the management of projects framing acknowledges that project management scholars departing from a traditional prescriptive approach are bound to focus on a linear execution of the project. The traditional prescriptive roots of the project management discipline neglects the need for developing managerial and design strategies that can evolve over time in order to respond to changes in the set of benefits the project is expected to deliver (Miller & Lessard, 2007). Prescriptive approaches fail to encourage project managers to think outside a plan put together at the early stages when the environment was different. For those reasons, scholarly literature encourages professional bodies to extend the range of capabilities for project management in line with a more holistic view of the practice (Morris, 1994, 2011). Project managers need not only to be a master of the traditional skills. They also need to emphasize context, understand the importance of delivering an outcome that will benefit the project customers, and understand how the needs from multiple actors are likely to be affected by the delivery of the project (Morris, 2011). Awareness of the importance of managing risks at the early project stages, and of the almost disproportionate impacts that these early stages have on the quality of the project delivery, is at the basis of calls for improving the quality of front-end strategizing (Gil, Beckman, & Tommelein, 2008; Miller & Lessard, 2007; Morris, 2011). One approach that seems promising is to explore ways to further the integration of front-end strategizing practices with options logic, the topic discussed next.

## 2.2 Real Options: Theory and Practice

At the heart of the options logic is the notion that organisations can make capital investments upfront in the definition of the new developments in order to mitigate the impacts of potential upside and downside risks that they foresee might occur over the lifecycle of the developments. The basic principle of real options theory posits that organisations want to assess whether the possibility of delaying specific investment decisions in order to reduce the downside risks or increase the upside risks compensates for the extra costs those organisations need to incur upfront to postpone the investment decision (Copeland & Antikarov, 2001; Insead & Levinthal, 2004; Kogut & Kulatilaka, 2004). The application of real options theory to gauge strategic investments decisions in complex institutional environments – as it is the case of strategic investment in complex infrastructure business ecosystems – can be overwhelming. The modelling of the strategic investment problem can require an investment in arduous mathematical apparatus and demand modellers to make an extensive number of assumptions (Bowman & Moskowitz, 2001; Lander & Pinches, 1998). To cope with these difficulties of applying real options theory to decisions unfolding in complex institutional environments, a number of alternative approaches have emerged in recent years. In the following sections, this research explores these alternative approaches and identifies opportunities for integrating options logic with more conventional risk management practices.

### 2.2.1 Financial options: The origins of real options theory

An option is the right, but not the obligation, to choose a course of action (Dixit & Pindyck, 1994). In the financial markets, where options first started to be used, an option gives the owner the opportunity to buy (call option) or sell (put option) a stock at a specified price on a specified date (expiration date) (Amram & Kulatilaka, 1999). This flexibility can be extremely valuable to investors in the presence of uncertainty about the future value of the assets. The possibility to wait for new information enables the investor either to reduce the downside risks, or to realize the upside potentials. The flexibility thus generates a positive value to investors by delaying decision-making, also called “holding premium” or “time value” (Dixit, 1992).

In the world of financial options there are two basic types of options: calls and puts. With call options, the owner of the option pays a fee to have the right to buy the equity for a fixed price in the future. A clever investor will exercise this right if at the time of expiration of the option its equity price in the market is higher than the exercise price (right side of point p in Figure 2.1 A). Therefore, the investor can exercise the right of buying the equity for the exercise price and immediately sell it for the market price, making some profit. With put options, the owner of the option has the right to sell the equity for an agreed price. Again, the investor will only exercise this right if this decision is favourable, i.e., only if the market price is lower than the exercise price. Therefore, the investor can exercise the right of selling the equity, avoiding major losses even if the equity price falls under the exercised price (right side of point p in Figure 2.1 B).

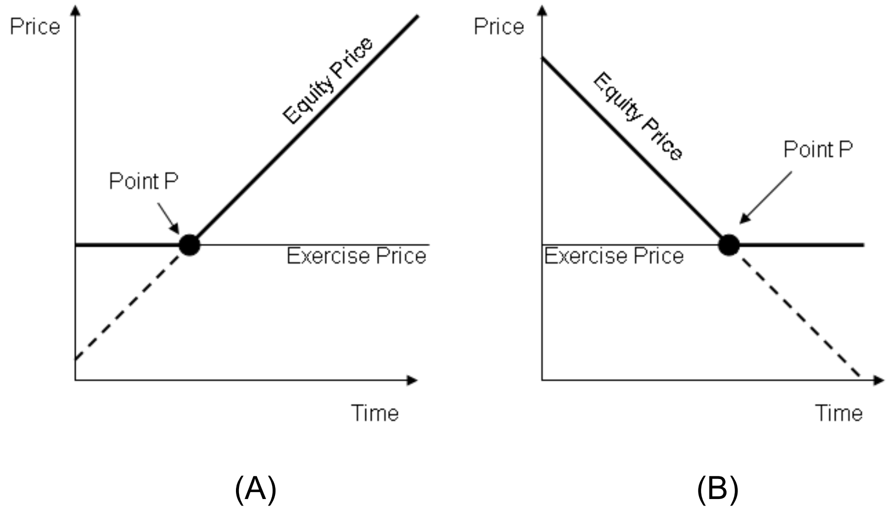



**Figure 2.1: Schematic representations of the rationale behind call and put options (adapted from Hull 2008)**

In terms of the time to exercise, options can be categorized either as European or American options. A European option can only be exercised at a fixed future date, whereas an American option can also be exercised at any time before this fixed date (Smit & Trigeorgis, 2004). Both the type of option and its categorization in terms of the time to exercise determine which analytical models need to be used to assess the option value. To undertake this assessment, specific knowledge about the investment is also required. In the case of financial options, the following variables affect the option valuation (ibid):

- the value of the underlying asset (stocks, commodities, currencies, etc.);
- the strike price – the price at which the option is exercised;
- the time to expiration – explicitly set at the time of the option purchase;
- the risk-free rate of interest – the interest rate that the investor can obtain from an investment without private risks;
- the volatility of the value of the underlying asset – the uncertainty about the value of the underlying asset which can be represented by the standard deviation of these values from the average value over a certain period.

In financial options, these variables are relatively easy to quantify numerically by observing quantitative historical data which is readily available from the long history of tradable markets unless the nature of investment is totally novel. However, obtaining historical data to numerically characterise these variables becomes significantly more problematic when applying options theory to real assets, a branch of the literature called real options theory. For those reasons, the difficulties to quantify the variables have become a major obstacle to the dissemination of real options theory in the world of practice (Bowman & Moskowitz, 2001; Lander & Pinches, 1998), as explained in the next section.

### 2.2.2 Real Options Theory

Real options theory, or more exactly real options pricing theory, is a research stream that explores the application of financial option theory to nonfinancial assets such as an airport, a power station, or even a hospital (Amram & Kulatilaka, 1999; Smit & Trigeorgis, 2004). As in the case of financial options, an option reserves the right to the owner to take a decision in the future after environmental conditions have evolved. Therefore, when managing real assets the owner of the real option has the right to take a decision that will suit the owner without having to commit to make that decision in advance (Howell et al., 2001). At the heart of real options theory there are two main questions inherent to the nature of capital investments in real assets. First, how much is it worth investing to buy a selected option? Second, if an investor decides to buy an option, when should the option be exercised (Howell et al., 2001)? Real options theory proposes that the analysis of these questions is helpful to support managers to make capital investment decisions under conditions of uncertainty such as decisions to delay, expand, abandon, or reposition a capital investment (Smit & Trigeorgis, 2004).

Real options theory argues that traditional techniques to assess capital investments such as the traditional discounted cash flow (DCF) or net present value (NPV) models that estimate the future cash flows and discount them to a present value are of limited value under conditions of uncertainty about the future states of the world (Bowman & Moskowitz, 2001; Busby & Pitts, 1997; Smith & Nau, 1995). First, real options theory argues that these traditional techniques do not recognize the value of the flexibility built in the project definition to ensure the project can adjust economically to the eventual realisation of different scenarios that can be foreseen ex-ante (Bowman & Moskowitz, 2001; Lander & Pinches, 1998; Putten & Macmillan, 2009). Second, the theory notes these models base their estimations of future cash flows on forecasts and adopt a high-risk adjusted rate of discount to compensate for additional risks that the predictions may not materialise (Putten & Macmillan, 2009). Whilst not ignoring the difficulties to precisely predict future cash flows especially in very turbulent environments, the theory argues traditional models are too simplistic in the way they deal with uncertainty. As a result, traditional models tend to produce misleading insights because they rely on excessively conservative rates of discount. In contrast, real option valuations assume that the future is very unpredictable. Therefore, when analytically modelling an investment problem, real options valuations offer a way of reasoning that enables investors to allow for the postponement of a decision to when uncertainties get resolved. This flexibility offered by real options analytical models limits the risks that investors may incur if their predictions are inaccurate, which in turn allows investors to use a risk-free rate of return (Howell et al., 2001). Crucially, once a real options analytical valuation is adopted, the presence of uncertainty in the environment actually creates opportunities of upside gains for the investors (Amram & Kulatilaka, 1999). The more the environment is uncertain, the more valuable the option from a modelling perspective. However, whilst from an analytical perspective the option can become more value as uncertainty goes up, high uncertainty in the value of the option in the future can make it more difficult to persuade the investor to buy the option in the present (Gil, 2007).

Real options valuations use similar variables to those used in valuating financial options. However, the difficulties to numerically qualify the variables in the assessment of real assets are significantly higher than in the assessment of financial options. The value of the underlying asset, for instance, can be represented by the value of an oil platform, the price of a plot of land, or, in more complex cases, the benefit that a development can generate to a community. The valuation of these potential assets is clearly not easy to obtain from listings in the stock market. Likewise, the time to expiration of an option might be difficult to estimate. Unlike financial options, the expiration data does not need to be necessarily explicit in the investment contract. In some circumstances, it is even possible to have options that will never expire, i.e., perpetual options (Howell et al., 2001). Similarly, the cost to exercise the option can be particularly challenging when the time for the option to expire is far away in the future, or when multiple actors will have to chip in to fund the costs of exercising the option if uncertainties resolve in a favourable way. For example, if an upfront investment is made to safeguard underground land to build a railway tunnel in the future, it is still difficult to estimate precisely the construction costs if an investor is expected to exercise the option in 20 or 30 years time. Finally, the numerical determination of the appropriate risk-free rate of interest can also be challenging because there are many different rates of interest that are free of private risks and can possibly be selected to replicate the investment (e.g. treasury bills, stock market). Likewise, the numerical determination of the volatility can also represent a challenge in the case of real options because of the lack of historical data on the price of the underlying asset (McConnell, 2007).

These difficulties are not however impediments to using real options pricing theory. Some historical data is likely to be available that can be of help, and expert opinions can also be used to estimate those variables as accurately as possible. Numerical assumptions of these variables can then be used as inputs to assess a number of different types of real options (Lander & Pinches, 1998; Smit & Trigeorgis, 2004). The main types of options can be summarised as follows:

- options to defer: this option enables the holder to delay the investment and wait for more information about the environment before deciding whether to go ahead or not with the investment; they are especially useful for investors faced with an irreversible investment;
- options to switch inputs, outputs, or risky assets: – this is a reversible option that enables the holder of the option to make adjustments to the inputs or outputs of a given investment;

- options to abandon – this is an option that gives the holder the right to abandon or postpone a capital investment in case of an unfavourable evolution of the environmental conditions during the design, construction, or operation stages of an investment;
- options to alter the operation scale – similar to a switch option, this is a reversible option that allows its holder to change the investment in order to better accommodate variations in the environment;
- options to grow – this is an option through which the investor strategically structures the investment in a way that earlier stages of the investment are designed to enable subsequent stages aimed at growing capacity if conditions evolve in a favourable way; they are particularly suitable for investment situations that entail a number of projects that can be inter-related in a sequential fashion;
- options to stage investments – this is similar to options to grow, but the motivation to stage delivery is broader and not necessarily a question of growing capacity if the environment evolves in a favourable way;
- compound options – these are options that combine more than one type of the options listed above.

For each of these types of real options, different valuation techniques can be used. The decision of which valuation technique to adopt depends on the particular characteristics of the capital investment (Smit & Trigeorgis, 2004). Put differently, the valuation technique that becomes preferable is a function of a conflation of factors including the feasibility of making a large number of numeric assumptions for the different variables, and the most suitable type of option to frame the problem. Two of the most important real options valuation techniques are partial differential equations (such as Black-Scholes) and binomial trees.

Used for continuous time domains, the Black-Scholes models (Black & Scholes, 1973) provide a closed form solution to price an option. Through the Black-Scholes analysis it is possible to derive a partial differential equation, which makes it quite straightforward to obtain an accurate numerical solution for the value of the option over time (Wilmott, Howinson, & Dewynne, 1995). Modelling options with this technique can be seen, however, as a complex black-box formulation to anyone without a solid mathematical background (Fichman, Keil, & Tiwana, 2005). Also, the need to simplify the formula to make it suitable to real options analysis requires a number of non-trivial assumptions. The Black-Scholes formula assumes, for instance, that the value of the underlying asset will fluctuate randomly through time with a constant volatility. Put differently, it assumes that this process can be formally described by the random walk theory of the Geometric Brownian Motion (GBM). This assumption might seem unrealistic in valuating real assets, or even risky if applied blindly without a proper understanding of its limitations.

Contrary to the Black-Scholes formula which assumes continuous movement in the price of the asset, the binomial or lattice models (Cox, Ross, & Rubinstein, 1979) use discrete points in time to estimate the value of an option. These models can be built without requiring the use of very complex math. They can be more easily customised, and they are relatively transparent and flexible (Copeland & Tufano, 2004). Succinctly, the binomial approach requires to: (1) figure out the range of possible values that the underlying asset can take assuming that these values will range at a constant volatility; and (2) work back from the expire date the value of the option at the various points in time when a decision can be taken during the capital investment lifecycle. The use of a 'random walk' on a regular lattice (Cox et al., 1979) to model possible variations in the value of the asset in a complex system is justified when this process can be assumed to vary along a steady long-term trend in the same way that prices for stocks and other publicly traded assets evolve. Assuming the value of the underlying asset will fluctuate according to GBM is satisfactory in several cases. Conversely, there are instances in the real world in which the variables modelled cannot be represented by a stochastic process similar to GBM, and accordingly these variables should be modelled following a mean reverting stochastic process (Dixit & Pindyck, 1994). A mean reverting stochastic process assumes that the value of underlying asset will revert to the equilibrium and tend to move to the mean price in the long term. If the characteristics of the investment require the adoption of a mean reverting stochastic process to represent the fluctuation of the value of the underlying asset, the modeller needs to undertake more mathematical work. However, for investment analysis where small differences are not important, this additional mathematical work is not necessary as the results are almost unaffected by the use of mean reversion rather than GBM (Metcalf & Hassett, 1995).

### 2.2.3 Applications of Real Options Models

There have been many applications of real options in the last decades that vary in the analytical models used to quantify the different variables (Amram & Kulatilaka, 1999; Tom Copeland & Antikarov, 2001; Howell et al., 2001; Trigeorgis, 1996). Most of these models start by identifying a fundamental problem related to strategic decisions to invest in capital assets and use real options analytical tools to produce a model that can help the investors to decide the extent to which they want to put money in the investment given the options that can be built in the investment. Brennan and Schwartz (1985) is one of the first to adopt real options to support the investment decision in natural resource projects and use the analytical tools to determine when to begin and end operations on a copper mine example. Based on the prices obtained from the copper market, Brennan and Schwartz were able to advance theory to practical applications and generate policies for developing, managing and abandoning options. Similarly, Siegel, Smith and Paddock (1987) use real options price models to analyse offshore oil properties. They compare their approach with the DCF approaches, discuss ways to estimate the option parameters, and justify the use of the analogy of underdeveloped oil reserves with oil stock prices. More recently, Borison (2005) makes an important contribution and discusses the difficulties of implementing real options in an oil and gas example for the purposes of illustrating the mechanics of the approaches.

Less conventional approaches – in which the use of stock prices as proxies for the modelling is less straightforward – have also been developed in the recent years. Neufville, Hodota, Sussman and Scholtes (2008), for instance, originally combine real options theory with decision analysis to assess the value that an investment in R&D can create to the potential development of a new IT system. More specifically, they analyse a particular case of a capital investment to develop and deploy an intelligent transportation system (ITS) to avoid collisions at intersections. The system required the integration of computer devices installed inside the cars with devices located alongside the roads. The analysis illustrates that the investment in R&D that is a prerequisite to develop this new system is worthwhile, whilst a full upfront commitment in the system would not be advisable given high uncertainty in the environment. The upfront R&D investment is necessary to leave open the possibility furthering the development and implementation of the system considering a large potential for achieving great success, but also acknowledging a significant possibility of failure. This application of real options theory to a real-world investment decision illustrates how a hybrid methodology that combines real options theory with some standard decision analysis techniques can be an effective approach to assess the value of investing in innovative transportation systems. The case application is also successful in using decision analysis to undercut the difficulties to make some of the numerical assumptions in pure real options models.

The case aforementioned consists of a single application of real options theory to assess capital investments with potentially very large payoffs due to the huge savings obtained with the prevention of accidents. In these cases of sharp asymmetry between capital investment and potential revenues, small inaccuracies on the numerical assumptions might not have a significant influence to the extent they change the recommendations of the final outcome. This is often the case when applying real options theory to model investment problems that pertain to strategic decisions about options *on* projects (Wang & Neufville, 2005). The same relationships is unlikely to extend however if real options theory is applied to model investment situations where the asymmetry between the cost of the option and the potential value is not sharp. This is exactly the case for example investors face if they try to apply real options theory to assess the option value of more mundane decisions where the payoffs might be small and small errors can completely modify the final decision, the so-called options *in* projects (Wang & Neufville, 2005).

In recent years, methods that combine real options theory with other established analytical techniques to assess investments have surfaced, leading to even more analytically sophisticated approaches. For example, Trigeorgis and Smit (2009) develop a methodology that integrates real options valuation with game theory principles in order to valuate infrastructure expansion investments. Their valuation methodology aims to determine whether the growth options that can be built into an infrastructure asset may be over- or under- priced in a competitive setting. Using the case of Schiphol airport, the authors demonstrate that much of the value of the investment in airport infrastructure comes from hypothesized growth in the airline industry rather than from the infrastructure itself. The authors argue their novel methodology offers a superior analysis than those available through conventional net present value methodologies because (a) it factors in the influence of potential strategic moves by rivals (b) it enables to account for the tradeoffs between making limited investments in flexibility to allow for future expansion and pre-empt moves by competitors and postponing any sort of investment at risk that future opportunities will have to be foregone.

Unsurprisingly, the major challenge with extending these complex analytical models to other strategic investment decisions in real assets is the difficulties to operationalize certain aspects of the options games modeling and making the required numeric assumptions. Prior work shows that, even for applications of sophisticated models to macro strategic investment decisions, many input variables need to be numerically estimated and many simplifications need to be undertaken to adjust the models to real-world conditions and ensure the models remain analytically tractable (Bowman & Moskowitz, 2001; Lander & Pinches, 1998). This problem can be expected to become even greater when attempting to apply the theory to model more mundane investment decisions that pivot primarily around early design decisions that need to be made at front-end strategizing. By their nature, these design decisions are going to be many, and many may be interrelated (Gil, 2009). At the same time, the potential payoff of each option may be limited. The problem of applying real options theory to evaluate a portfolio of interrelated options is significantly more complex than using the theory to price a single option. Furthermore, many assumptions need to be made in order to keep the models tractable (Wilmott et al., 1995). Because of the limited payoffs, the final recommendation of the models also becomes significantly more sensitive to errors in numerical assumptions. The limited potential payoffs also restricts the amount of resources an organization can put to model a set of mundane design decisions. Ultimately the size of the investment required for analytically modeling an investment decision around multiple interrelated mundane options built-in might not payoff the potential benefits that such investment could produce.

These challenges for applying the real options analytical approach to strategic investment decisions have long been recognized. Bowman and Mozkowitz (2001) for example note the difficulties in making reliable numeric assumptions, and in modelling the relationships between variables in a way that the model remains an accurate representation of reality. Along the same lines, Insead and Levinthal (2004) point out a critical feature that interferes with its applicability. They note that the valuation of financial options is an exogenous process that is not influenced by the investor’s activity and that the market signal of option value is easily observable. These two assumptions seldom work for the case of real options pricing. The more these two assumptions are violated, the more difficult to show rigour in the application of real option analysis. Likewise, Lander and Pinches (1998) discuss a number of reasons that have systematically put off practitioners from adopting real options models to support capital investment decisions. First, decision-makers may not have the skills necessary to understand the mathematical models that accompany applications of real options theory. Second, the need to reduce the complexity of the mathematical models and ensure they can remain tractable requires numerous simplifications that limit the capability to model relevant problems. Clearly, the difficulties in implementing real options analytical models to mundane investment decisions pivoting around design decision-making problems have limited their applications to engineering design projects and construction projects (Ford et al., 2002; Neufville, Scholtes, & Wang, 2006).

Despite the difficulties encountered to adopt the analytical pricing models, practitioners have been encouraged to adopt the formal reasoning behind options appraisals to support strategic investment decisions. Fichman et al. (2005) call it option thinking, i.e., a new way of thinking about how to promote flexibility in capital projects to create value without necessarily requiring the organisation to undertake analytical modelling and make numeric assumptions. The idea of using qualitative options thinking is not new. Busby and Pitts (1997) found in their survey with industrial firms that most senior finance officers made investment decisions aligned with the logical relationships in real options theory, despite not necessarily being aware of the literature. Intel was one of the first global organizations to use options thinking when designing contracts for acquiring expensive tools for its semiconductor fabrication facilities under conditions of extreme uncertainty (Peng, Erhun, Hertzler, & Kempf, 2012; Vaidyanathan, Metcalf, & Martin, 2005). Since then, options logic has become almost mainstream practice in procurement activities that unfold under conditions of uncertainty: clients and suppliers agree on a contract where the client commits to buy an X number of assets upfront, and agrees to pay for a fee (an option) for having the right to increase the number of assets to buy in the future, under commercial terms and conditions that the supplier committed to at the time the client bought the option. These types of practice have become common for example when airlines place orders to buy aircraft from Airbus (Stonier, 2001).

More recently, the use of options thinking has also been observed in procurement and design of infrastructure developments. Lee (2007) shows evidence that a UK health trust has adopted options thinking when writing up the commercial contracts for procuring a new hospital through a private finance initiative. This scheme aimed to award the responsibility from construction and decades of operational activities to a private entity, albeit significant uncertainty in the evolution of health care practices and technology that could require changes to the design of the hospital itself. In essence, the trust was asking the PFI entity not only to price the cost of building the hospital and operating it, but also to price for the eventual need to adapt the assets in the future to accommodate pre-specified changes that the trust could foresee ahead. Another example is Gil's (2007) empirical study of Heathrow airport's Terminal 5. It shows that intuitive use of options thinking informed the development of the design brief that instructed the design team to safeguard the economical adaptation of the terminal to future foreseeable changes.

The use of options thinking at the commercial interface between different firms has also been explored in less capital-intensive industries. Nagali et al. (2008) for example show evidence of how options thinking have been applied by Hewlett-Packard (HP) in the development of a quantitative framework to support procurement (Procurement Risk Management – PRM). This framework helps managers to deal with high uncertainty in product demand, component cost, and component availability. It uses options thinking to help both firms (manufacturer and supplier) identify a portfolio of structured contracts with appropriate quantity and pricing of components. By using options thinking to define a risk-shared contract, all parties benefit from a win-win situation since the risks associated with demand, cost, and availability of components are reduced both for the client and suppliers. Building upon Tiwana, Keil and Fichman (2006) work (at the firm level), Hult et al. (2010) conducted a survey whose results also provide evidence that supply chain managers use options thinking when dealing with uncertainty.

All in all, evidence shows that there is a clear interest of decision-makers on options thinking both to design the practices internal to the firm as well as to design the commercial interfaces between the firms. Evidence also shows, however, that implementing real options mathematical models might be overwhelming and off-putting to practitioners. This suggests that alternative approaches are required to adequately deal with strategic capital investments under conditions of uncertainty. Lander and Pinches (1998) argue that qualitative modelling frameworks that build on options thinking offer an alternative to mathematical models. This is precisely the purpose of real options reasoning, a qualitative approach to deal with uncertainty discussed next.

### 2.2.4 Real Options Reasoning

Real options reasoning offers an alternative approach to guide strategic decision-making under uncertainty (McGrath & Nerkar, 2004). This approach uses the logic of real options to assess the value of flexible solutions, but it relaxes the quest for exact results. In doing so, real options reasoning aims to better align the financial theoretical background with managerial practice which has been reluctant to explore the value of formal options logic (McGrath & MacMillan, 2000). Different authors have developed various methods based on real options reasoning approach in a number of different fields.

In the arena of new technology projects development, for instance, McGrath and MacMillan (2000) present a method to help practitioners assess the value of alternative projects under conditions of uncertainty. The method uses fuzzy measures necessary to make conjectures, which are informed by previous projects, and intentionally avoids the precise quantification of the ultimate value of the options. Rather, the method requires users to systematically list all the factors that can possibly affect the value of a technology option. More specifically, these factors are inputs of a framework that reveals the lesser or greater potential of the alternative technology options. Figure 2.2 illustrates the logic of this framework. The final value of the option is a function of the potential upside gains derived from the option less the costs generated by creating the option. The upside gains variable, in turn, is a function of cumulative revenues less the commercialization costs. Each of these factors is then subdivided into a list of several statements that influence the value of the technology options. Finally, this list is used to guide discussion among managers, who have to score their agreement/disagreement with each statement and collectively reach a decision.

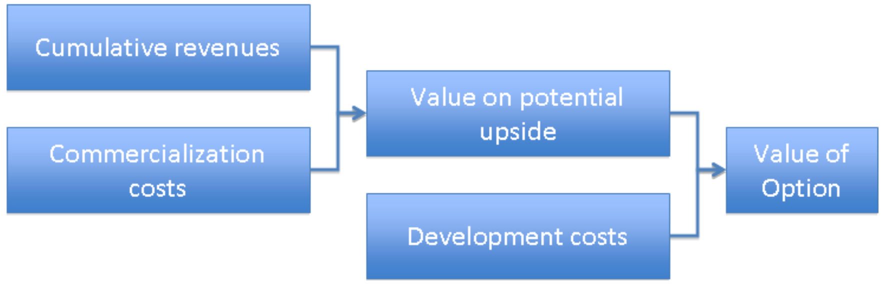



**Figure 2.2: Framework of the factors that determine the value of a particular option (adapted from McGrath and MacMillan 2000).**

Similarly, MacMillan et al. (2006) develop a method that combines Discovery Driven Planning (DDP) and options logic to overcome the difficulties originated from the high number of numeric assumptions required for decisions on technology investments. DDP involves a number of steps for systematically planning how to assign and check the assumptions made under conditions of uncertainty (McGrath & MacMillan, 1995). The integration of DDP and options logic aims to provide a clearly defined sequence of key checkpoints at which DDP should be used to test the assumptions and convert them into knowledge as new data is uncovered. These checkpoints are usually associated with major events that are likely to provide useful information to adjust the assumptions. This method also incorporates sensitivity analysis to define the critical assumptions that most impact the final decision and that need to be tested for accuracy in the future as uncertainties get resolved. Finally, using simulation to vary each assumption within a range of possible outcomes, the method estimates the project value, by compounding the net present value and the option value of the technology investment. The main purpose of the method is not to define a precise total value for a technology investment, but to select and assign resources to the best projects using relative values (MacMillan et al., 2006).

In the Information and Communication Technologies (ICT) infrastructure investments arena, Angelou and Economides (2008) develop a framework that combines real options analysis and Analytical Hierarchy Process (AHP) to prioritize investments on a portfolio of ICT projects. Since the valuation of these projects is influenced by both tangible and intangible factors, the authors develop a multicriteria decision analysis framework. It involves pair-wise comparisons amongst project candidates, uses real options theory to quantitatively assess tangible factors and uses the AHP to assess the intangible factors. Similarly to the McGrath and MacMillan’s (2000) work, this framework lists a number of potential benefits and costs against which potential projects will be assessed. Tangible costs and benefits are assessed using the expanded NPV, i.e., the total value obtained by the combination of the static NPV with the value of future options built in the investment. Intangible costs and benefits are qualitatively assessed due to the difficulties in attempting to numerically assess these variables. Comparisons between the performance measures of candidate projects are then computed to rank the projects. Using this methodology to rank a portfolio of ICT investment decisions for a growing water supply and sewerage company, the authors show that the consideration of intangible factors in the valuation changed the final ranking of the preferred projects compared to the analysis that had only considered tangible factors.

Similar to the integration of different methods to advance analytical methodologies to assess strategic investments, the combination of different literature streams has also been used in approaches that exploit the power of options logic that put less emphasis on analytical methods. For example, Miller and Waller (2003) propose a strategic planning framework that combines the qualitative reasoning of scenario planning methodologies with the quantitative valuation of the real options analysis. Scenario planning encourages decision-makers to think systematically about possible future states of the world. This is about encouraging decision-makers to envision a number of scenarios, describe them qualitatively, and to devise qualitatively strategies to best cope with those scenarios in case they actually occur. Real options analysis, in contrast, provides the mathematical apparatus necessary to develop an appropriate response to manage upside and downside risks that are the outcome of the realisation of foreseeable scenarios. Miller and Waller’s (2003) work links the two approaches into a framework to support decision-making on capital investments. This involves the following sequence of steps: (1) envision and articulate possible states of the world; (2) identify environmental uncertainties that can affect business performance; (3) propose and assess specific steps to manage risk, i.e. real options investments; and (4) strategically implement and recurrently reassess these real options investments as the foreseeable uncertainties get resolved.

Driouchi, Leseure and Bennett (2009) further elaborate on Miller and Waller's (2003) work and assess the human, social and political factors that affect strategy formulation. They develop a framework to support decision-making on strategic investments that integrates real options reasoning with Problem Structuring Methodology (PSM). Rather than relying on sophisticated analytical modelling, PSM provides a structured guidance to help decision-makers in dealing with the firms' future strategic commitments. By incorporating options thinking in the mechanics of PSM, the authors argue their methodology facilitates the participation of people at all levels of the organisation in the debate for assessing different alternatives and generating solutions. This approach also aims to integrate the impact of social and political factors on management decisions and facilitate the visualisation of the implications of decisions based on diverse possible scenarios. The applicability of their tool is illustrated through the application of a decision on how a hypothetical multinational company should expand geographically. The framework asks decision-makers to first determine a range of choices based on a number of future possible scenarios. Each of those choices can be subdivided into further options and viewed as a sequence of compound options. Subsequently, the acceptability of each sequence is assessed in terms of whether it is desirable, acceptable, unacceptable, or catastrophic. Finally, after assigning a specific weight to different performance criteria, the ratio of desirable or acceptable sequences to the total number of sequences is calculated to represent the final assessment for each alternative location. Importantly, the authors argue that the value of the framework lies primarily on the guidance and assistance that decision-makers received through the process of using the tool rather than on the precise final assessment that the tool produces.

Along the same lines, Suh, Weck and Chang (2007) have developed an options-based framework to support design decisions in the car platforms. The value of the platform designs itself can be very small relative to the value of more conventional capital investments, e.g., an airport or a highway. However, the design decisions on car platforms actually have major capital implications because in many ways the designs will determine the expensive tools that manufacturers need to buy and have to live with for perhaps one or two decades. In this regard, strategic commitments in platform designs are not dissimilar from other strategic capital investment decisions. Suh et al's (2007) options-based method aims to support engineering design teams to assess investments aimed at building flexibility in the design of car platforms. Using a combination of quantitative analysis and expert engineering knowledge, this method encompasses a sequence of seven steps: (1) identify uncertainties in functional requirements; (2) relate uncertainty in the requirements to specific design components; (3) define the bandwidths for different variables, i.e., estimate how the range of values for the variables affect the final results; (4) identify critical functional elements for flexibility; (5) determine design alternatives; (6) determine the costs and benefits for each design alternative; and (7) analyse how uncertainty in functional requirements affect the outcomes of the different design alternatives. The use of the method aims to help decision-makers select which functional components of the platform have the best potential to embed flexibility, and to build flexibility in the design of the platform accordingly.

## 2.3 Final considerations

The discussions above show how literatures on the management of projects and real options have advanced theories in their respective fields. It describes how these two research streams have succeeded in producing theory, procedures, and tools to help managers shield performance of their undertakings from foreseeable uncertainty in the environments in which they operate. Interestingly, however, the review also shows that the two fields have hardly intersected. The combination of the two theoretical lenses represents a major opportunity to further understanding on the management of capital projects. Admittedly, this combination is not trivial. Capital projects unfold in complex institutional environments that involve multiple stakeholders with different mental models, capabilities, knowledge bases, and planning horizons – a level of institutional complexity that is seldom captured in the real options literate. In the world of practice, as in the world of theory, both fields remain stubbornly separated. On the one hand, the management of projects literature has long recognised that project management practices that pivot around an execution-oriented approach are largely inadequate to cope with constantly changing environments (Flyvbjerg et al., 2003; Lenfle & Loch, 2010; Morris, 2011; Shenhar & Dvir, 2007). Recent works have only started to give steps in the direction of improving the quality of front-end strategizing by elucidating on the complementarities between conventional risk management and design flexibility (Gil & Tether, 2011). On the other hand, real options theory shows great potential as a framing that can be adopted to improve the quality of front-end strategizing. However, the emphasis of real options theory on quantitative approaches has made it difficult to apply this framing to capital project front-end strategizing.

All in all, Suh et al's (2007) options-based method to support front-end strategic investments on platform design remains the closest to the purpose of this research. Unlike product development environments, design decision-making at the front-end of capital projects is rarely a process internal to one organisation. Rather, more often than not decisions at capital project front-end strategizing are likely to impact many organisations that are entitled to influence those decisions because they may have legitimate stakes in the project outcome (Gil et al., 2012; Gil & Tether, 2011). This institutional complexity needs to be taken in consideration in any attempt to use options logic to support design decision-making at capital project front-end strategizing. Different stakeholders may operate with different planning horizons, different wherewithal to make investment decisions, and bring different knowledge bases and technical capabilities to bear in the decision-making process (Chapman & Ward, 2003). Under conditions of uncertainty, different stakeholders can also be expected to assess the value of designing in particular options differently – a research question that is explored further in the empirical studies presented in the next chapters. In summary, the research presented next combines the two research streams reviewed here to address a fundamental question: how to design and develop capital assets that can evolve and cope economically with changes in design requirements during project delivery and the operating life cycle? The next chapter will explain the method adopted to respond to the question at the heart of this study.

# 3 Research Method

This section describes the method adopted to investigate the research questions posed in Chapter 1. It first explains how the research is designed and justifies the selection of each research task and how they relate to each other. Subsequently, the importance of the development of capital infrastructure projects is presented, explaining how the particular empirical settings chosen represent a suitable instantiation of the issues affecting the development of these assets. Each task is then described in detail, explaining how they answer the research questions. The exploratory case study sought to understand the difficulties of using real options models in front-end strategizing infrastructure capital projects and to what extent project teams use options thinking when making upfront design decisions under conditions of uncertainty. The case studies complement this initial investigation by exploring to what extent the use of options thinking is also adopted during negotiations of multi-stakeholder teams. Finally, the two-group controlled experiment explores the usability of adopting a formal design for evolvability framing in front-end strategizing. The chapter concludes by presenting the strategies undertaken to ensure the validity and reliability of this research.

## 3.1 Research Design

The research method involves two interrelated stages (illustrated in Figure 3.1). In the first stage, I conducted fieldwork studies in order to build a conceptual understanding of the extent to which the notion of design for evolvability is applied in real-world projects, namely through future-proofing design practices. I used literature in the area of real options to make sense of the empirical data collected through an exploratory case study and a subsequent embedded case study with the capital project division of Network Rail (NR), using three different capital project designs as the units of analysis. The main aim of the studies undertaken in this first stage was to gain understanding of the use of options logic in front-end strategizing and to shed light on the reasons why options pricing tools are rarely adopted by practitioners to support the development of capital infrastructure projects. These initial studies were fundamental to the subsequent stage of this research as they set the foundations for the inductively conceptualization of a proof-of-principle of a method.

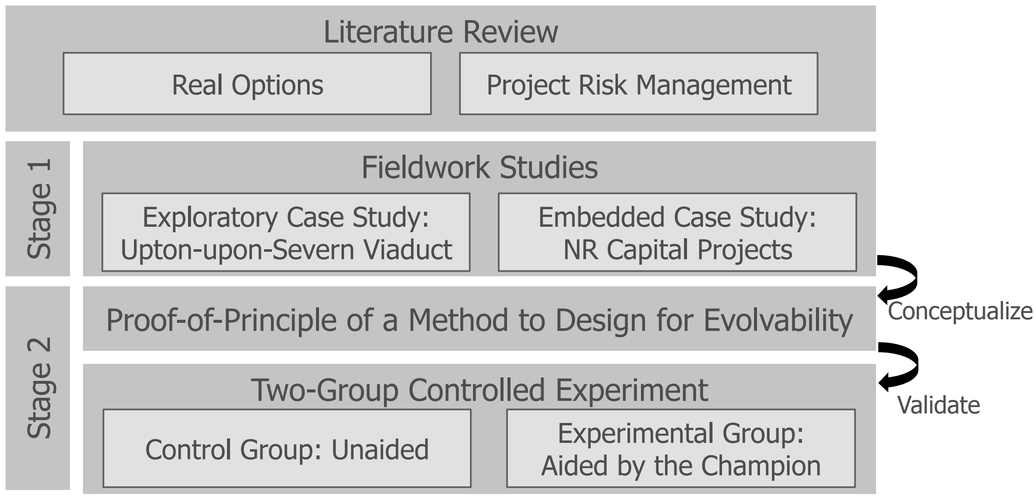



**Figure 3.1: Research method**

The second stage of the research method involved a two-group controlled experiment aimed at producing insights on the value of formalising a design for evolvability framing in the early design stages of a capital project. To this purpose, I produced a proof-of-principle of the framing by cross-fertilizing the empirical insights from the fieldwork against literature in real options reasoning and project risk management. Describing real-world projects and cross-fertilizing this empirical understanding with the current literature was fundamental to adequately prescribe a proof-of-principle that accounts for the lack of use of options thinking in the design decision-making of infrastructure capital projects. I also developed a hands-on simulation exercise of the early stages of a real-world capital project which was empirically grounded on a NR capital project. Multiple project teams were subsequently formed to play the hands-on exercise. Half of the teams were asked to resolve front-end strategizing for this capital project without adopting any particular formal framing, and the other half was asked to resolve the front-end strategizing following the proof-of-principle. To assess the results of the experiment, I used comparative analysis of qualitative data and statistical analysis of the results of a survey on the usability of the formal framing. The next sections provide further details on how each of these tasks was performed.

## 3.2 Empirical Setting

This research is empirically grounded in capital projects to develop new infrastructure assets. These large-scale developments typically unfold under conditions of high uncertainty in requirements that trigger design change requests. The projects are also characterized by the need for large capital investments, and the involvement of numerous stakeholders with heterogeneous and often conflicting aims. It is in light of the characteristics of this empirical setting that this study proposes to investigate its core research question: *how to design and develop physical infrastructure assets that can adapt and evolve economically to cope with changes in design requirements, a.k.a. future-proof infrastructure?*

To undertake exploratory fieldwork around future-proof designing, I first undertook a case study on the development of the Upton-upon-Severn Viaduct. This viaduct has been recently designed so that its deck can be raised in the future in order to stay above the maximum expected level of flooding in the area, a typical environmental hazard in the region. The flexibility to elevate the deck can be handy if the local authority finds funding to raise the elevation of the highway that includes the viaduct as it would avoid having to demolish the new viaduct. Put differently, the flexibility to raise the level of the deck means the design of the viaduct can cope economically with the realisation of a foreseeable change in the level of the highway in the future. This project was run under a tight budget and design decisions were made primarily jointly by two main stakeholders: the design consultant and the local authority. The design choices that were made offered an opportunity to investigate the rationale behind the practice of future-proofing.

To further the empirical understanding of design for evolvability practices, I subsequently undertook fieldwork with the capital projects division of Network Rail (NR). NR is the owner and operator of most of the rail infrastructure in Great Britain. From a commercial perspective, NR is a private organisation operating as a business but limited by a public guarantee. A guarantee company does not usually have a share capital or shareholders, but instead has members. These members do not have any financial or economic interests in the company, which means that they do not receive dividends, share capital or any other form of payment from NR. All profits are, therefore, available for re-investment in the rail network system.

Although the projects in which NR gets involved either as a supplier or as a client vary in size, value, complexity, risk, and many other parameters, a common hallmark of these capital projects is the need to develop railway assets that can be economically adapted to changes in functional and operating requirements during their long service lifetimes. However, developing capital assets that can cope with foreseeable changes in requirements may require additional capital expenditure. Finding ways to finance this additional investment in design for evolvability can be difficult especially in times of austerity as the capital resources could be spent in investments that are more attractive and reliable in the short-term. In third-party projects wherein NR plays the role of supplier (e.g. railway station enhancement projects sponsored by a local authority), the problem of whether to invest further capital to ensure an asset can cope economically with foreseeable change in the future is compounded by the clients' poor technical understanding of the rail industry and financial constraints. In these cases, project sponsors may be reluctant to endorse an additional upfront capital investment that may pay off only in a distant future and only if uncertainties resolve favourably.

### 3.2.1 Exploratory Case Study

The empirical setting of the exploratory case study is a £3.5M project to design and construct a new viaduct carrying the highway A4104 over the River Severn floodplain, the Upton-upon-Severn Viaduct. The project received the Construction

Award and the Overall Project Award from the Institution of Civil Engineers (ICE) West Midlands in 2005, for its ‘ingenious and practical [design] solution’. This award-winning project provided an ideal case study to explore in-depth both empirically and analytically the practice of design for evolvability as its design solution was centred on whether to build an option to elevate the deck to ensure the viaduct would not need to be demolished if the whole highway gets elevated in the future. The ‘future-proofed’ design was well documented (Sreeves, 2007), which permitted a rigorous investigation of the rational underpinning the future-proof design. More specifically, the exploratory case study aimed to probe (a) the drivers of the decision to design for evolvability, and (b) the extent to which the variables and relationships in formal options logic were factored in the design decision-making process.

The data collection process involved primary and secondary data, including discussions with the principal bridge engineer at Halcrow Group Ltd., the design consultant firm, and archival documents such as technical reports describing the design of the viaduct (Sreeves, 2007), press releases, minutes of meetings at the project front-end, clips from the local press, funding bid documentation, and the feasibility study for the project. Technical notes on other viaduct designs, as well as design standards (e.g., design manual for roads and bridges) helped to compare and contrast the characteristics of this particular viaduct with more traditional design solutions. The analysis of the data[2] was informed by the theoretical constructs in real options and included the following steps: (1) identification of the upfront uncertainties in design requirements and the extent to which these uncertainties got resolved in the early design stages; (2) comparison of the value of the alternative design concepts that were explored at the early stages based on the information that was available at the time when a design decision had to be made; (3) investigation of the extent to which intuitive options thinking was used to choose one design concept over the other alternatives; and (4) analytical assessment of the value of the alternative design concepts based on real options pricing methods.

[2] Further details on how the data was analysed are provided in chapter 4.

The exploratory case study yielded two main insights. First, designers use intuitively options logic to make design decisions; and second, the application of options pricing methods would fit poorly with the problem of making mundane design decisions. The exploratory case study also revealed a setting where design decisions were made by two key actors: the design consultant, a specialized firm contracted to design the viaduct; and the public sector client, a stakeholder with limited knowledge on infrastructure design practices. Capital projects, however, tend to unfold in complex organisational settings. Often, not only two, but various actors get involved in front-end strategizing these projects, because they have legitimate stakes on the project outcome. This limitation of the exploratory case study motivated the examination of a second case study grounded in the world of NR capital project design, in which the decision-making process typically involves multi-stakeholder project teams.

### 3.2.2 Understanding Capital Project Design Decision-making in Multi-project Stakeholder Environments: The Case of NR Capital Project Design

This case study explored capital project design decision-making practices in the context of the NR infrastructure division. It was an embedded case study (Yin, 2003) wherein the large unit of analysis was NR's capital project design process and the embedded units were the front-end strategizing of three distinct projects. One key condition for the selection of these particular projects was the existence of design practices that involved the need to build provisions to cope with future changes in requirements. The sample selected varied the size of the project and the organisational complexity of the organisation involved in the design of each capital project. Such a variety in the selection of the projects allowed an adequate representation of NR's capital project design process.

The purpose of the embedded case study was two-fold. First, it aimed to investigate the extent to which multi-stakeholder project teams intuitively use option-like thinking to make upfront design decisions under conditions of uncertainty; and second, it aimed to investigate whether the multi-stakeholder teams would use any rules of thumb to prioritise options, assess desirable levels of design flexibility, and agree on which investments should be made in design optionality. These two aims were explored across three projects: (1) the £15M Arpley Chord enhancement project, whose scope mainly consisted of installing a new chord line to connect two important railway lines; (2) the £150M Reading Station redevelopment project, whose scope encompassed a programme of works to modernize and increase the capacity at one of the busiest railway stations in the UK; and (3) the £12M Salford Crescent Station redevelopment project whose scope encompassed a programme of works to reduce the critical overcrowding problems at the platforms of this station.

#### 3.2.2.1 Collecting Data

Data access was facilitated by a senior NR programme manager who worked as a key informant. Between February 2010 and August 2011, I was an academic-in-residence at NR for purposes of data collection. I was given rights to visit the office of the NR Infrastructure Investment Division in Manchester; had limited access to the company's intranet; and was introduced to the staff. Data collection mainly involved semi-structured interviews, identification and collection of relevant documents, and observations at the headquarters in Manchester as well as on particular project sites.

Overall, I conducted over 20 formal and informal interviews with NR staff and external stakeholders. It consisted of 8 formal one-on-one interviews with NR staff (e.g., project managers, engineers, risk managers, commercial sponsors) and 3 formal one-on-one interviews with representatives of the project clients and other key stakeholders for the three projects in the sample. The development of an interview protocol (Appendix A) ensured the interviews would touch upon a number of key issues related to design for evolvability. Each interview lasted between one and two hours. I also conducted over 10 informal interviews with NR staff. The purpose of these informal interviews was mainly to: (1) understand the interviewees' role in the projects they were involved with, as well as the projects themselves; (2) understand NR's design decision-making practices in general and (3) present and obtain feedback on the research objectives and preliminary findings. All interviewees were identified through a snowball approach (Biernacki & Waldorf, 1981).

To triangulate the findings with other sources of data I searched information of NR projects and processes, which are well documented on the intranet as well as on the internet. I also searched the corporate intranet for documents such as project briefs, public consultation reports, corporate information, capital development procedures, and threads of e-mail conversations. Another source of data was notes from sitting-in on a number of project meetings. I observed 8 internal meetings where design decisions were discussed by the project teams, namely the value management and risk assessment meetings. I also sat in one of NR's annual general meeting, where I could learn more about the corporate vision for the long-term. Finally, I organised two workshops to receive feedback from preliminary insights from the case studies, research method, and the rudiments of the proof-of-principle. Figure 3.2 illustrates how the triangulation of the findings was undertaken (as suggested by Yin (2003)), as well as the validation of the preliminary findings through the workshops.

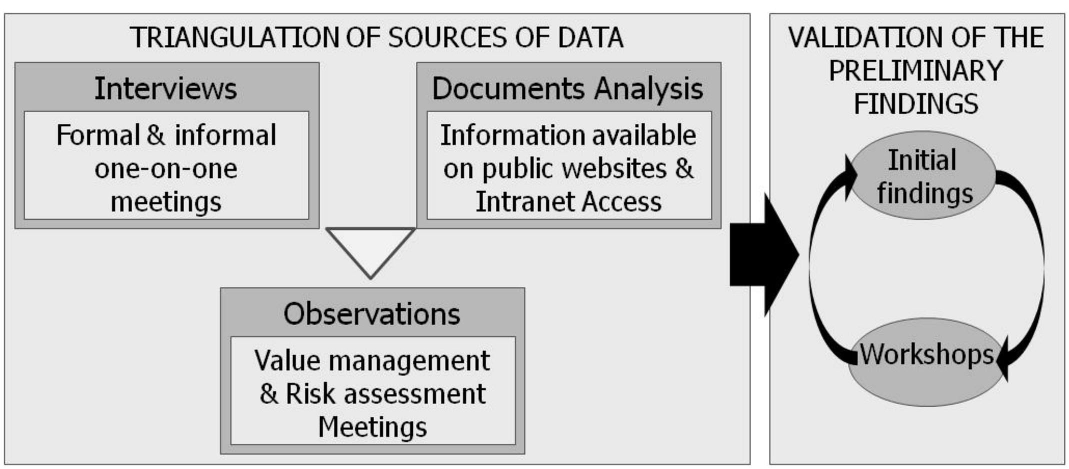



**Figure 3.2: Triangulation of sources of evidence and validation of preliminary findings**

People involved in the aforementioned data collection activities had diverse job roles, backgrounds, and levels of experience. The more experienced people had participated in several projects and, as a consequence, were fully aware of NR's processes relevant to capital design. More specifically, I sought to understand in-depth the NR lifecycle approach for designing and managing capital projects termed the Governance of Railway Investment Projects[3] (GRIP). To reduce possible biases from collecting data from just one organisation I collected information of the key external stakeholders for each project. This involved collecting documents publicly available (minutes of meetings, corporate vision and progress reports, press releases, consultation drafts) as well as interviewing staff from the external organisations. People that were interviewed usually held very senior positions, which enabled the research to capture the main interests and priorities of these organisations.

#### 3.2.2.2 Analysing Data

All the interviews, meetings and workshops were tape-recorded and transcribed. This ensured the accuracy of the information obtained from the participants, and made it possible to return to the data as many times as necessary. To ensure the rigour of the data analysis I adopted template analysis: a procedure that suggests how to summarize and organise the data in a hierarchical form to make it meaningful (King, 2008). It also provides guidelines on how to build categories or themes relevant to the research question through the use of an analysis guide or a 'codebook'. This approach was important to accurately describe the design processes conducted within the different cases and to identify which variables decision-makers factor in during design decision-making. The empirical insights from the exploratory case study and from the embedded case study at NR were cross-fertilised with real options and risk management literatures to develop a proof-of-principle on a formal design for evolvability framing to apply to capital projects (as seen in Figure 3.1). In addition, one of the NR case studies – the

[3] The GRIP process is further explained in chapter 5.

Salford Crescent Station redevelopment project - was transformed into a hands-on exercise. This project was chosen because of its characteristics. It was not overly complex, institutionally, like that of the redevelopment of the Reading station wherein key design decisions were the outcomes of lengthy multilateral negotiations. It was neither too simple, like the Upton-upon-Severn viaduct in which key design decisions were made by just two stakeholders. The Salford Crescent project provided a context for the two-group controlled experiments, through which the impact of introducing a formal design for evolvability framing to project performance was investigated.

### 3.2.3 Proof-of-Principle Development

As part of my research methodology I developed a proof-of-principle of a method to design for evolvability, which I used to investigate the potential impact to project performance of adopting a formal design for evolvability framing in real-world capital projects. The proof-of-principle resulted from cross-fertilizing literature on real options reasoning and project risk management with the empirical insights from the exploratory case study of the Upton-upon-Severn viaduct and the fieldwork on NR capital design practices. The proof-of-principle encourages project teams to follow a step-by-step procedure based on options logic to help them reason as to which options should be designed in, which party should pay for the capital investment, why those options should be designed in, and when the options are likely to be exercised. The proof-of-principle also proposes establishing checkpoints similarly to the way MacMillan et al. (2006) propose in their work (see section 2.2.4 for details). Design decisions related to optionality can then be reassessed at these checkpoints to ensure the adequacy of assumptions made in the previous stages.

The development of the proof-of-principle was an iterative process as it was refined in light of deeper insights through the empirical fieldwork. The first phase of the development of the proof-of-principle entailed a comparison between the design steps of the exploratory case study and the steps proposed by other methods available in the literature (section 2.2.4). As expected, those methods had to be slightly adjusted due to particular characteristics of the empirical settings, in which they operated, dissimilar from those in the infrastructure sector. A later refinement was undertaken after I conducted the informal one-on-one interviews and the two workshops delivered with NR employees.

### 3.2.4 Two-group controlled experiment

With the proof-of-principle established (Chapter 6) I conducted a two-group controlled experiment for learning about the overall impact of a formal design for evolvability framing on front-end strategizing. The experiment consisted of assembling teams of students tasked to collectively resolve the design definition of a specific project. The contextual data for this experiment was obtained from the case study of the £12M Salford Crescent Station redevelopment project. At the heart of the front-end strategizing for this middle-sized project was the need for teams to think and decide collectively whether they were willing to fund any design provisions to enable the redeveloped station to adapt economically to foreseeable changes in the future. Teams were given background information corresponding to conventional outcomes that would have been produced in the initial stages of the GRIP process for the project.

The experiments were conducted with three different groups of students: (Student Group 1) MBA students enrolled in a New Infrastructure Development elective course; (Student Group 2) graduate-standing students from a business school enrolled in an MSc programme on Operations, Project and Supply Chain and (Student Group 3) graduate-standing students from an engineering school enrolled in an MSc programme on Management of Projects. The students had no previous experience in the case study to avoid any previous knowledge influencing their decisions. In total, 107 students took part in the experiments distributed across 17 teams (8 aided and 9 unaided). Although there are no indicators that could suggest the sample is biased in some way, a larger sample would be necessary to identify trends and make more general inferences.

Two types of experiments were organised: one involving the control group and one involving an experimental group. The control group did not receive any additional help to resolve the design problem, whereas the experimental group benefited from the involvement of an additional student-participant – the ‘champion of design for evolvability’. This participant received a document explaining their role and how they were expected to try to persuade the multi-stakeholder team to follow the method to design for evolvability to support design decision-making. I also personally trained the champions of design for evolvability through one-on-one workshops. By comparing the performance by the different teams, with and without the involvement of the champion of design for evolvability, the experiment enabled to test the overall impact of a design for evolvability framing on front-end strategizing. Experimental designs involving an experimental group and a control group are suitable to assess proposed cause-effect relationships because they enable to determine whether a particular process causes some expected outcome(s) to occur, and to compare the experimental results with the outcomes of the control group which does not implement the process (Trochim, 2006). This ability to produce evidence on comparable situations that isolates the process from other potential causes of the expected outcome gives strong internal validity to experiments (ibid).

The experiment transformed one of the value management meetings on the Salford Crescent project into a hands-on exercise. The main aim of the exercise for each team was to collectively produce a front-end project strategy encompassing both a design strategy and a funding strategy. The teams needed to decide (a) whether provisions should be built into the design of the station to cope with foreseeable changes in requirements; (b) the level of capital investment into building these provisions; and (c) who would pay for these provisions. To do so, participants needed to assess and compare a number of design alternatives. The information needed to assess the alternatives was provided in the design briefs. Each participant had a role and specific information associated with that role, but not necessarily one participant had all the information needed in their brief. Hence, participants needed to interact in order to build a collective understanding of the different alternatives and get to a position where they would feel confident to discuss trade-offs and negotiate compromises.

Each of these experiments lasted around three hours on average and consisted of four main phases:

- Induction;
- Training of the champions of design for evolvability;
- Value management exercise;
- Closing, de-briefing and feedback.

During the induction, which lasted no more than 1 hour, participants were informed about the aim of the experiment and the research project, the structure of the experiment, and the tasks they needed to undertake. Each participant was assigned a specific role in the multi-stakeholder project design process. Project roles consisted of representatives of external stakeholders such as the train station manager, university, and local council. Other roles pertained to NR job positions including the project manager, the commercial sponsor, and the project engineer. Admittedly, the number of stakeholder representatives involved in the actual project was higher than the number of roles created for the experiment. Only the key stakeholders (the same that were involved in the real value management meeting) were included in the experiment. Even in the real-world, value management meetings during which different stakeholder must make decisions upon design solutions seldom involve all the relevant stakeholders.

To make the participants familiar with their roles, each participant received two briefs a week before the experiment session: (1) a general brief detailing the key design alternatives for the project (circa 3,500 words); and (2) a specific role brief explaining the role each participant takes in the project and the aims (circa 1,000 words each). Each participant was also given access to additional archival information related to the role that they could access online. The additional information aimed to improve the participants' general knowledge about the organisations they were representing and included documents such as the organisation's strategic vision or the NR route utilization strategy. Participants were also reminded of the variety of information available to them on-line about these large organisations. The distribution of the reading material along with the induction session took place one week before the actual exercise, which allowed participants sufficient time to read the material and prepare for the exercise.

Although the participants were encouraged to read thoroughly the material to absorb as much information about the project as possible, it was expected that not all of them would do so. This uncontrolled factor is not dissimilar from real-world project environments where scarcity of time can render professionals unable to prepare properly to a meeting by reading the available and relevant information. Constantly managers lack sufficient time to prepare for meetings in advance, especially at the project front-end (Morris, 1994). Participants may put more or less effort to study relevant documentation ahead of a meeting. In the real-world people may be incentivised to prepare for meetings because that is their job; here the incentive was the opportunity to learn about the process and/or the getting a good grade in the related coursework.

The participants performing the role of the champion of design for evolvability received a specific brief containing the instructions needed to steer the multi-stakeholder teams through the front-end strategizing process using the design for evolvability proof-of-principle. The champions of design for evolvability also received training on the mechanics of the design for evolvability proof-of-principle in an additional session in which I personally explained the key points and responded to any questions. This training lasted circa 1hour.

During the actual exercise (Figure 3.3) participants had to take part in a 2-hours value management meeting during which they had to identify the elements they needed to factor in for making their decisions, understand the information available (even if distributed across different participants), as well as understand which assumptions they needed to make because information they would ideally need was unavailable. All teams performed exactly the same tasks, i.e., they had to collectively produce a front-end project strategy. The ultimate goal for each team was to narrow down the number of design alternatives, recommend one design solution that should progress to the next design stage, and indicate what provisions would be incorporated in the chosen design solution to cope with future needs.

**Figure 3.3: Photo of a two-group controlled experiment session**

Each team had to submit the project strategy and the meeting minutes to summarize the main discussions they had in the value management meeting held during the exercise. Student Group 1 and 2 had to submit these documents as part of the course assessment, which ensured a 100% turnout of written feedback. Student Group 3 had to present their project strategy and reflect on the main issues they faced during the meeting as well as participate in a debriefing session after the hands-on exercise. These presentations informed the collective discussion helpful to obtain feedback from participants about the impact of the proof-of-principle on front-end strategizing. The presentations and the debriefing sessions, which together lasted approximately 50 minutes, were tape-recorded and transcribed. I also observed parts of the value management meetings of the Student Group 3. I made notes about participant's remarks, tactics, and posture during meetings, and interviewed some groups to obtain additional feedback. I observed teams from Student Group 1 and 2 during their entire value management meeting; the whole process was tape-recorded and transcribed. The variety of strategies used to obtain feedback from the different groups of students ensured that potential problems arising from the lack of commitment of participants were kept to a minimum. As in the case studies, template analysis was used to aid a systematic examination of the data obtained from the documents submitted by the students and from the debriefing session transcripts.

All the 107 participants in the experiment were asked to complete a questionnaire at the end of the exercise and 101 questionnaires were returned. This last task took less than 10 minutes. I chose questionnaires to be able to compare measurements of user satisfaction between students that undertook the front-end strategizing process unaided against those that undertook it aided by a champion of design for evolvability. Questionnaires are a reliable data collection method because: (a) they are able to provide a quick response to a number of closed questions; (b) they reduce fatigue of respondents that otherwise would have to participate in more time-consuming interviews; (c) they avoid the effects that the interviewer may have on participants; and (d) they complement the findings obtained from the qualitative discussion using a slightly different approach (Bryman & Bell, 2007). The questionnaire (Appendix B) used a Likert scale, ranging from 1 (strongly agree) to 7 (strongly disagree) to capture the perception of the participants in a symmetric way. In summary, the various sources of data collection obtained from the two-group controlled experiments included: observations of the experiments and interviews, notes and transcripts from debriefing sessions, coursework documents (meeting minutes, project strategies, individual reflection assignments), and questionnaires on the overall satisfaction with the front-end strategizing process.

#### 3.2.4.1 Validation

The approach to test the validity of the proposition that a formal design for evolvability framing adds value to front-end strategizing followed El-Tayeh and Gil (2007) approach in validating an IT proof-of-principle (IDRAK) of a method to support the work of geographically-dispersed design teams. In their approach, teams of students are tasked to use IDRAK to play the Delta Design exercise online and others to play the board version. The Delta design consists of a board-based exercise that simulates collective design process involving a structural engineer, thermal engineer, project manager, and architect that have to develop a two-dimensional building concept that meets the needs of a client (Bucciarelli, 1994). In the exercise, each participant receives an objective function for their role (Bucciarelli, 1994). By comparing exercise performance data between the two experiments (board and digital), El-Tayeh and Gil (2007) assess the performance implications of using a digital interface to support the work of geographically-dispersed design teams.

The validation approach in this research, however, is slightly different. Here, the two-group controlled experiment simulates a project environment that captures the 'fuzzy' and multi-stakeholder nature of the project front-end strategizing. Hence in this environment stakeholders have ill-defined roles and unclear – if not ambiguous – objective functions. In addition, the experiment is structured to explicitly capture a tension between short-term affordability and long-term adaptability that affects collective design decisions in capital projects. Whilst some stakeholders may not be in a position to fund their design preferences, they may still see themselves as a project 'client' and perceive both their short-term and long-term preferences as entirely legitimate requests.

To test the extent to which a formal design for evolvability framing adds value to the front-end project strategizing effort I compared assessments of the usability of the value management meeting in the two environments (aided by a champion of design for evolvability and unaided). Usability is "the effectiveness, efficiency, and satisfaction with which specified users can achieve goals in particular environments" (ISO, 1998, p2). Usability can be operationalized through objective and subjective criteria (Folmer & Bosch, 2004; Hornbæk, 2006). The objective criteria capture aspects of the interaction that are not dependent on people's perceptions such as the quality of the outcome, itself a measure of the effectiveness of the interaction. The subjective criteria capture people's perceptions of, or attitudes towards, the interaction, including satisfaction and efficiency (Hornbæk, 2006). I used various instruments to collect objective and subjective data about effectiveness, efficiency, and satisfaction as explained next.

Effectiveness focuses on “the accuracy and completeness with which users [of a system] achieve specified goals” (ISO, 1998, p2). Traditional measures of effectiveness include accuracy, completeness and quality of outcome (Hornbæk, 2006; Sauro & Kindlund, 2005). Efficiency focuses on “the resources expended in relation to the accuracy and completeness with which users achieve specified goals” (ISO, 1998, p2). Traditional measures of efficiency include measures of time, input rate, mental effort, and communication effort (Hornbæk, 2006; Sauro & Kindlund, 2005). In the experiment, I assessed efficiency achieved in the value management meeting by analysing the quality of the conversations as documented in the meeting minutes, in the reflective practice assignment, and in qualitative responses to the questionnaire. The observations of the meetings and of the debriefing sessions provided additional data. Specifically, I examined the extent to which the participants understood the objectives and concerns of other participants, and the extent to which the project participants succeeded in building a common understanding of the design process.

Finally, satisfaction focuses on “the freedom from discomfort, and positive attitudes towards the user of the product” (ISO, 1998, p6). Traditional measures of satisfaction include perceived usefulness and ease of use (Davis, 1989; Lewis, 2002), preferences, users’ attitudes, and perception of outcomes/interaction (Hornbæk, 2006; Lewis, 2002). Surveys are typically used for measuring satisfaction (Folmer & Bosch, 2004). This research adapted Lewis’ (2002) Post Study System Usability Questionnaire (PSSUQ), which assesses satisfaction in terms of three dependent variables: system usefulness, information quality, and interface quality. Each variable is an aggregate construct of an independent set of statements; satisfaction, in turn, is an aggregate construct of three dependent variables (see Appendix B for details of the structure of the questionnaire). The results of the questionnaires on the participants satisfaction with the front-end strategizing process were triangulated with qualitative data from the interviews with the group of students, the reflective practice assignments and the debriefing session. Table 3.1 summarizes which instruments of data collection were used to compare the assessments of the usability of the value management meetings between the teams that were aided by a champion of design for evolvability against those teams that did not receive additional support.

**Table 3.1: Summary of measures of usability and respective instruments of data collection**

| Measures of Usability | Main Assessment Objectives | Instruments of data collection |
|---|---|---|
| Effectiveness | Assess the quality of the deliverables produced through front-end strategizing | Analysis of strategic recommendation |
| Efficiency | Assess the quality of the conversation during the front-end strategizing process | Analysis of meeting minutes; reflective practice assignment; interviews and debriefing sessions; observations |
| Satisfaction | Assess participants overall satisfaction with the front-end strategizing process | Questionnaire (quantitative); qualitative assessments in reflective practice assignments; interviews, debriefing sessions |

### 3.3 Research Validity and Reliability

Although qualitative researchers cannot fully step outside their own experience to obtain an observer-independent account of the experience, they should develop a strategy to address particular threats to validity and reliability (Maxwell, 2004). Validity is concerned with the integrity of the conclusions generated from a piece of research, whereas reliability is concerned with whether the results of a study are repeatable (Bryman & Bell, 2007). Maxwell (2004) argues that validity and reliability are closely related since the failure to generate repeatable conclusions from the same events (reliability) is expected when each observer fails to generate their conclusions with factual accuracy of their account (validity). To address these threats, the following research strategy was undertaken.

First, the research sought to increase the construct validity, i.e., the degree to which the operational measures used are legitimately representative of the concepts being studied (Yin, 2003). To this purpose, I used multiple sources of evidence including interviews, observations, and document analysis to reduce the possible bias of the interviewees when conducting both the exploratory case study and the embedded case study on design practices. Occasionally, I found necessary to clarify whether different words used interchangeably by practitioners actually meant the same concept or not, as in the case of practitioners' use of the terms 'options' and 'alternatives'.

Second, the research sought to increase internal validity, i.e., the problem of knowing whether there is causal relationship between two events that cause an event *x* leading to an event *y*; if the researcher fails to identify that a third event *z* may have caused the event *y* to happen, the research design has failed to account for internal validity (Yin, 2003). This issue was particular important to the analysis of the two-group controlled experiment. To increase internal validity, with the exception of adding the champion of design for evolvability into the experimental groups, all the other conditions of the experiment remained exactly the same for the two groups. Design briefs were systematically given one week ahead of the experiment to ensure students would acquire the knowledge needed to play the role. The groups were given the same amount of time to resolve the front-end strategy for the project, and all design for evolvability champions received the same amount of training.

Third, the research sought to increase external validity, i.e., the extent to which one can extend the findings from one study to a different context (Maxwell, 2004). More specifically, internal generalizability refers to the generalization of the findings within a sample study of people, events or setting that were not directly observed. Conversely, external generalizability refers to the generalization of findings from within communities, groups or institutions. The research sought to increase the generalizability of the research findings within the world of capital infrastructure projects by using empirical findings from two fundamentally different empirical settings to inform the design of the proof-of-principle on design for evolvability. Of course the two-group controlled experiment is grounded on the world of NR capital design practices, which arguably limits the validity of the research insights to very dissimilar capital design settings. External generalizability may, thus, be seen as one of the limitations of the research findings. It merits further research whether the research insights apply to different design environments. This would require replicating the research in other settings providing issues of reliability were carefully observed.

Finally, the research sought to address the reliability of the findings. According to Yin (2003), a reliable research demonstrates that the operations of the study can be repeated, achieving the same conclusions and findings. He argues that the goal of reliability in the research design is to minimize the errors and biases in a study. To achieve that, it is fundamental to document all procedures in a systematic way. This research addressed these issues, by documenting all the steps taken during the case study investigation, such as developing formal protocols for interviews and detailed accounts of the empirical findings. In addition, the two-group controlled experiment was carefully documented allowing its replication in the future. The methods used to assess the experimental data on the extent to which the design for evolvability proof-of-principle adds value were also carefully documented and borrowed from well-established and reliable methodologies to assess the usability of proof-of-principles in the digital environment. In addition, an instructor’s guide was developed to make it easier for researchers to replicate the experiment in the future (appendix C).

# 4 Exploratory Study: Uncovering Design for Evolvability Practices in Single-Funder Capital Project Environments

## 4.1 Introduction

This exploratory case study aimed to investigate the extent to which the notion of design for evolvability informs capital design practices, and if so, explore the nature of the decision-making process underpinning decisions to design for evolvability. Specifically, the study aimed to investigate the motivations to design for evolvability, identify the key elements affecting the design decision-making process, and tease apart any eventual rules informing the decisions as to whether optionality should be built in the design of capital projects. To this purpose, the exploratory study focused on the decision-making process that led to the development of the award-winning design for the new Upton-upon-Severn viaduct in the UK in 2005. The Upton-upon-Severn viaduct offered a suitable setting for this exploratory investigation for three main reasons. First, the design of this project has received a number of awards for its future-proofed approach, the practitioner's jargon for a design for evolvability approach to capital projects. Second, the capital design setting was relatively simple as it basically hinged on a dyadic relationship between the local authority (the project sponsor and funder) and the engineering consultant appointed to develop the design. This institutional simplicity reduced the noise that could otherwise mask efforts to uncover the key variables and decision rules at the heart of the design decision-making process. Finally, the project was well documented in the technical press and its key actors were accessible to discuss it.

The most salient feature of the design for the Upton-upon-Severn viaduct were the provisions built upfront in order to allow the deck to be raised at a reasonable economic cost if the highway is elevated in the future. The highway crosses a flood plain at a relatively low elevation, and periodic flood events are a recurrent problem in the region that has detrimental effects to the local economy. These events also contributed to accelerate the deterioration of the former viaduct replaced by the new one. To investigate the nature of early design decision-making for evolvability in a capital setting this exploratory case study focused on the future-proofing practices. Methodologically, the study complements the qualitative analysis of the empirical findings with an analytical model using real options pricing methods. The qualitative analysis plays the empirical data in archival documents and collected through interviews against literature in real options reasoning, design, and projects. The analytical model aims to assess the economical value of the ‘future-proofed’ viaduct. To this purpose, the study models the underlying economic value of the viaduct as a Geometric Brownian Motion (GBM) ‘random walk’ (Cox et al., 1979). It also models the possibility of raising the deck in the future as a switch option (Smit & Trigeorgis, 2004).

The main contribution of the qualitative part of the study is to reveal that an intuitive as opposed to formal and structured use of real options reasoning underpins the practice of future-proofing capital designs. The analytical component of the exploratory study in turn points to the inadequacy of using options pricing methods to support relatively mundane concept design decisions, even if they occur in an uncomplicated institutional setting as it is the case of single-funded projects. These findings motivate a subsequent empirical study on future-proofing practices in more complex capital projects wherein early design decision-making unfolds in a multi-stakeholder context – the topic discussed in the subsequent chapter.

## 4.2 Research Context

The Upton-upon-Severn viaduct project aimed to replace a 1939 reinforced-concrete viaduct over the low-lying floodplain to the east of the River Severn, Worcestershire, UK. This viaduct carried the A4104 highway, which offers an important crossing of the River Severn. It also represents a vital local link for the town of Upton-upon-Severn, which has the reputation of being the most flooded town in Britain (BBC, 2012). The 1939 structure of the viaduct was suffering from serious corrosion problems as a result of being periodically flooded – every five years, on average, the floodwater would rise above the road level. Over time, the corrosion problems evolved into serious structural problems that had compelled the Local Authority (LA) to impose a weight restriction and one-way reversible traffic working within the centre of the road (Figure 4.1). Whenever flood events forced the LA to close the road, the drivers had to undertake major detours. This situation had significant detrimental impacts to the local economy and quality of life of the community as it delayed the traffic of goods and the access to local facilities, as well as the access for emergency vehicles.

**Figure 4.1: The old viaduct during an imposed one-way reversible traffic**

The severe structural problems of the viaduct and the strategic importance of the highway to the town of Upton-upon-Severn made it imperative for the LA to quickly replace the old viaduct. The ideal scenario would be to elevate the whole highway and the deck of the new viaduct so that future floods would not force the LA to close the highway to traffic. Elevating the whole highway, however, would require a much higher capital investment than just replacing the old viaduct with a new one. It would also involve a lengthy planning approval process, as the LA would need to acquire more land to build higher embankments along the highway. Faced with a sense of urgency for replacing the obsolete viaduct and affordability limitations, the LA quickly framed this alternative as not viable.

Instead, the LA was more inclined to invest in replacing the old viaduct with a new one. The new asset would need to meet two criteria. First, the design loads should be based on a life expectancy of the asset of 120 years (assuming maintenance works at 20-year intervals) in order to meet the design guidelines in the BS 5400–1 (British Standards, 1988) and the design manual for roads and bridges BD 36/92 (Highways Agency, 1992). This meant that the viaduct would need to be designed to last 120 years, even if built at a level where flood events would inundate the highway periodically. Second, the design of the viaduct should factor in the possibility that the LA would want to elevate the whole highway in the future – flood events caused significant traffic disruption that could range from hours to several days. For example, the highway was closed for 10 days during a flood event in November 2000.

It was up to the design consultant appointed by the LA to devise a solution that would satisfy the needs of its customer in terms of: (1) urgency to replace the existing structure, (2) keep solutions within the LA's envelope of affordability, and (3) avoid premature technical obsolescence of the structure due to future inundations of the deck. The design process for the new viaduct started in 2003 with investigations of the conditions on site. Construction began in 2004 and the project was completed in April 2005. The execution of the selected design adopted pre-cast and preformed components to speed up the construction and minimise the construction works at the flood plain. The next section describes in detail the uncertainties informing the early design decision-making process, as well as the alternative technical solutions that surfaced during this project front-end strategizing process.

## 4.3 Front-end Strategizing

Many uncertainties informed the design decision-making process on the development of the Upton-upon-Severn viaduct. The stochastic occurrence of flood events was a key condition that needed to be factored in the design of the new viaduct, especially with regards to setting the elevation of its deck. In this region events which lead to floodwater rising above the highway occur every five years on average, and these events render the road impassable for several days. Records from the Environment Agency showed that, first, at least six complete closures of the road had occurred between 1947 and 2004; and second, the floodwaters had overtopped the A4104 or at least threatened to overtop it in another 17 events. If the deck of the new viaduct were designed at the same level as the existing highway, the effects of the extreme flood events would be twofold. First, the floodwaters would submerge the deck of the viaduct whenever the highway would get submerged. Second, the structure of the viaduct would need to be designed to stand flooding conditions, so as to avoid premature corrosion due to the ingress of de-icing salts in the structure. In light of the aforementioned conditions, four alternative concepts emerged:

- Multi-span integral viaduct with raised deck;
- Economical pre-fabricated viaduct with deck at the current level;
- Multi-span integral viaduct with deck at the current level;
- Multi-span modular viaduct with built-in option to raise the deck in the future.

The design of a multi-span integral viaduct with a deck at a higher elevation would ensure that the viaduct would always stay above the water level, even under extreme flooding occurrences. Technically, this solution would require raising the deck level by at least two meters (from the current 12.42m level to 15.15m). This new deck level would guarantee the minimum required air gap between the height of a 1:100-year design flood (13.75m) and the level of the bottom part of the deck, following guidance from the Environment Agency. This solution would require preparing a planning application for building a viaduct at a higher elevation. The need to build embankments supporting the new viaduct at a higher elevation would require, however, appropriating more land on both sides of the existing highway boundary. This in turn meant that the LA could be faced with a relatively lengthy planning approval process. In addition, this alternative was likely to increase the project costs even if it was more affordable than proposing to elevate the whole highway. Estimates conducted by the LA suggested that £3.85M would be needed just to elevate the immediately adjacent segments of the highway if the deck would be built at a higher elevation, roughly duplicating the capital cost of the investment. A sense of urgency for replacing the obsolete viaduct combined with issues of affordability made this scenario unattractive.

The second alternative consisted of building a relatively economical new viaduct at the same elevation of the old viaduct using pre-fabricated concrete or corrugated steel culverts. The culvert sections could be laid quickly side-by-side to support the viaduct, while allowing the floodwater to flow through. Pre-fabricated culverts are typically available in standardized sizes with heights that can range from 600mm to 3000mm; culverts with non-standard sizes can also be made to order. Whilst cost effective and fast to execute, this option had some drawbacks. Not only is a culvert-based viaduct less pleasant aesthetically, but it also requires increasing the overall length of the viaduct in order to guarantee the same area of flood openings relatively to a built-on-site multi-span viaduct. The rigidity of a culvert-based viaduct would also mean that the new viaduct would need to be demolished if the LA wanted to elevate the highway in the future.

A third alternative involved building a new viaduct at the same elevation of the existing viaduct, but using a traditional multi-span structure built on site as opposed to a solution based on pre-fabricated culvert modules. Aesthetically, this alternative was significantly superior. The necessary length of the multi-span viaduct to allow a sufficient flood opening area would be shorter than that for a culvert-based viaduct. That would make this alternative significantly less bulky. Similar to the previous alternative, however, the viaduct would also need to be demolished if the highway got elevated in the future.

The last alternative considered pivoted around building a multi-span viaduct at the same level of the existing viaduct, but with the built-in option to raise the deck at a reasonable economic cost in the future. This option would factor in the possibility that the LA was interested in elevating the whole highway in the medium- to long-term future. Leaving this option open would require designing the viaduct for different conditions: (1) the pillars supporting the deck would need to be designed with cantilevers at the top, sized for receiving the additional loads associated to seating lifting jacks and future vertical elements that would hold the deck at a new higher elevation; and (2) the design of the deck and the pillars would need to factor in the additional tensions associated with the deck elevation process.

### 4.4 Using Options Logic in Capital Design for Evolvability

After considering all the aforementioned alternatives, the LA opted to invest in a new multi-span viaduct with a built-in option to elevate the deck in the future at a reasonable cost. This solution consisted of eight spans of 17m, two spans of 14.5m, and cantilevers of 2.5m at each end of the deck, which altogether would cover the length of 170m of the existing viaduct. The analysis of the design process of the Upton-upon-Severn viaduct did not uncover any evidence that decision-makers used formal methods to compare the different alternatives and inform the choice for an alternative that would best pay off the capital investment and generate more value to the LA. Rather, the empirical findings suggest that the decision-makers assessed only informally the key aspects informing this decision, namely: (1) the overall costs and benefits of leaving open the option to raise the deck in the future; (2) the costs of exercising this option in the future; and (3) the costs and benefits of going ahead with a new viaduct design without a built-in deck-elevation option.

Notwithstanding this, the qualitative analysis of the design process suggests that the decision-makers intuitively used options logic when they were considering and comparing the alternative design solutions for the new viaduct. In their judgment, they also factored in important institutional constraints that ruled out some alternatives. On the one hand, the urgency to replace the viaduct ruled out any solutions proposing to elevate the deck of the viaduct. Even building just the viaduct with the deck at a higher elevation without elevating the highway would require building higher embankments at both ends of the viaduct. The feasibility study elaborated by the LA suggests that elevating the viaduct and the adjacent segments of the highway would require raising around 850m of road at a cost of approximately £7M[4]. Of course, elevating the whole highway would be even more time-consuming and costly as it would involve purchasing land outside the current highway boundary. To adopt this alternative, the LA would need to initiate a public inquiry and statutory procedures that would likely prolong the job by up to 5 years. On the other hand, aesthetic considerations and the need to preserve the minimum area of flood openings weighed heavily on the decision to rule out the culvert-based viaduct. Whilst an economical alternative, its rigidity made it unattractive as a culvert-based viaduct would have to be demolished if the highway got elevated.

Interestingly, the analysis of the meeting minutes and of the conversations with the principal bridge engineer suggest that an intuitive use of options logic was instrumental to help compare the alternative of building a viaduct with and without the option to elevate the deck in the future. Decision-makers agreed that the long-term benefits of building in flexibility upfront to elevate the deck in the future appear to pay off. Choosing a flexible design required an additional investment at the engineering design stage to put together an innovative technical solution and to guarantee the structural soundness of the deck for static and dynamic conditions. However, the empirical analysis of the design process did not uncover any data quantifying the estimated difference in capital costs between a rigid and a flexible multi-span viaduct. It did not, either, uncover any data comparing the estimated costs of exercising the deck-elevating option in the future against the costs of demolishing and building a new viaduct. The urgency to replace the viaduct and the relatively small scale of the investment created a situation where practitioners

[4] All costs are given in 2004 prices.

deemed unnecessary to undertake a quantitative options pricing analysis. As the principal engineer and project manager for the Upton-upon-Severn viaduct explained:

> "There was nothing scientific at all. An earlier preliminary design for a flood-free route over a much longer length of road identified an appropriate gradient. But this scheme needed land acquisition which couldn't be funded. The Upton scheme was an emergency scheme. However, the design did allow for future rising of the structure. Additional design and construction costs were minimal and no cost-benefit calculations were required."

## 4.5 Assessing the Flexibility Built-in

This section assesses the empirical findings using a traditional cost-benefit analysis and a real options analysis. The purpose is to tease apart the insights that these analytical assessments could have yielded if they had been applied to the case, and the challenges that decision-makers would have faced if they had chosen to do so.

### 4.5.1 Identification of Key Assumptions

Designing a viaduct that can be elevated requires upfront investments to build the design provisions. Specifically, building the option to elevate the deck requires additional reinforcement of both the pillars and the deck of the viaduct for dynamic loads associated with the elevation process. It also requires designing a larger space around the pile heads where the lifting jacks can be positioned (Figure 4.2). Expert assessments suggested that the overall cost of these design provisions added 10% to the construction costs of the viaduct. Since the actual cost of the viaduct was £3.5M, this puts the costs of building in this option around £350,000.

**Figure 4.2: Pile head with space for sitting lifting jacks**

The future investment to exercise the option will encompass the costs of positioning jacking up at the designated spaces, and the costs of raising the deck. Discussions with specialised contractors in the market suggest that the exercise cost, $C_{exe}$, can be roughly estimated at £500,000. If the viaduct were designed without the built-in option, it would have to be demolished and replaced by a new one once the highway got elevated. According to the feasibility study of the Upton-upon-Severn viaduct, demolishing the viaduct is estimated to cost £220,000. Assuming that a similar viaduct would be built, it is reasonable to estimate that another £3.15M would be needed to reconstruct it. Therefore, if the option is not designed in, the total adaptation costs to accommodate the new highway at a higher level are estimated to be £3.37M. In turn, the costs to elevate the immediately adjacent segments of the highway, if the deck of the new viaduct were to be built at a higher elevation, were estimated by the LA to cost £3.85M.

Besides the upfront investment and the necessary expenditures to raise the deck level in the future, the decision to build in the option also needs to factor in the costs of economic activities that will be foregone whenever the road becomes impassable due to an extreme flood event. These costs, hereafter called total costs $C_t$, are a function of the number of days of road closure $D_c$: The more days the road stays closed, the more it disturbs the lives of people in the area and the less economically attractive the viaduct becomes to the local community. These closures can escalate up to a point where they can even trigger the decision to elevate the highway and subsequently exercise the built-in option, i.e., raise the deck level. The total costs consist of the cost of diversion imposed to traffic $C_{div}$ and the costs to the businesses of the local community $C_{loc}$. The total costs are expressed by:

$$C_t = (C_{div} + C_{local}) * D_c \tag{4.1}$$

The cost of diverting the highway is based on the average cost of fuel per mile $c_d$, which can be estimated as £0.40 per mile of diversion per vehicle[5]; the distance that the diversion entails $d_d$, which is 11 miles in this case; and the number of vehicles circulating over the highway per year $Q$, which is estimated as approximately 5.1 million vehicles per year[6]. This can be expressed by:

$$C_{div} = c_d * d_d * Q \tag{4.2}$$

With the closure of the highway, people living in this area are cut off from local facilities such as the health centre, schools and local shops, unless they undertake a major detour. Based on the British Gross Domestic Product (GDP) £23,416[7] (or £64.15 in daily terms per capita), it is possible to estimate the possible economic losses to the local population (2,859 inhabitants) due to the highway closure. Hence, assuming for the sake of illustration that the diversion diminishes the local GDP per capita by 25%[8], the economic losses to the local community become:

---

[5] Based on the advisory fuel rates, as set by the HM Revenue & Customs to reflect actual average fuel costs from 2002/03 to 2010/11. Retrieved from http://www.hmrc.gov.uk/rates/travel.htm.

[6] Based on Worcestershire's Bridges Bid for Capital Maintenance Funding. Retrieved from http://www.worcestershire.gov.uk/cms/pdf/wcc-env-ltp-bridgesmajorschemebid%2011.pdf.

[7] In the United Kingdom the GDP, based on Purchasing Power Parity (PPP) per capita, was reported at 34,618.98 U.S. dollars in 2009, according to the International Monetary Fund (IMF).

[8] Assuming that business opportunities are forgone in quarter of a day.

$$C_{local} = GDP * p * 0.25 \quad (4.3)$$

where *GDP* is the estimation of the daily GDP per capita and *p* is the population of inhabitants (2,859 inhabitants).

In the Upton-upon-Severn viaduct, historical data from the Environment Agency shows that the highway was closed 15.18 days per year on average from 1988 to 2002. With equations 4.2 and 4.3, $C_{div}$ = £61,479 per day and $C_{loc}$ = £45,854 per day. Substituting these values into equation 4.1, the total costs per year ($C_t$) on average equals to £1.63M. The key assumptions that will be needed in the subsequent sections are summarized in Table 4.1.

**Table 4.1: Numerical assumptions for a discrete estimation of the option value based on single-point estimates**

| | Independent Variables | Single-point estimates (2004 prices) |
|---|---|---|
| a | Capital cost to build an integral viaduct at the elevation of the existing highway | £3.15M |
| b | Capital cost to elevate the adjacent segments of the highway if viaduct were to be built at higher elevation | £3.85M |
| c | Capital cost to build an integral viaduct at a higher elevation (a+b) | £7.00M |
| d | Capital cost to design and build in the switch option without including cost to elevate highway | £0.35M |
| e | Cost to elevate the viaduct in the future if option is built in at current prices (exercise cost) | £0.50M |
| f | Cost to exercise the option in the future including cost to elevate deck and adjacent highway segments (b+e) | £4.35M |
| g | Cost to elevate the viaduct in the future if option is NOT built in at current prices | £3.37M |
| h | Cost to elevate the viaduct in the future including cost to elevate deck and adjacent highway segments (b+g) | £7.22M |
| i | Average annual economic losses due to highway closures ($C_t$) | £1.63M |
| j | Annual interest rate | 5% |
| k | Annual inflation | 2% |

### 4.5.2 Base Case Analysis

The base case provides a comparison between the development of the Upton-upon-Severn design with and without the incorporation of the built-in option to elevate the deck in the future. Based on estimations of the most probable benefits and costs, it is possible to estimate the net present value (NPV) of a fictitious cash flow of these two design solutions and calculate the option net value (ONV) based on the difference between the two NPVs:

$$ONV = NPV_{withoption} - NPV_{withoutoption} \quad (4.4)$$

Each NPV depends on the potential economic benefits, crudely assessed in terms of a fraction of the national GDP that the viaduct provides to the community, discounted by the GDP-based costs of a highway interruption due to extreme flood events. A more sophisticated analysis would have to factor in other social benefits stemming from keeping the highway open to traffic, and less tangible social costs whenever the highway gets closed. For the purpose of this analysis, the benefits that the viaduct provides to the community are exactly the same for both alternatives, and therefore they do not need to be factored in the comparative analysis as one cancels the other. The economic losses stemming from highway interruptions due to extreme flood events are also the same for both alternatives, and similarly they do not need to be factored in the comparative analysis. However, the comparative analysis needs to factor in the capital investments required to build each design alternative since they are different. The design with the built-in option requires an additional capital expenditure (CAPEX), but a lower investment at the time of the highway elevation since the structure can be adjusted to the new highway level with limited adaptation costs in addition to the costs of elevating the adjacent segments of the highway. Conversely, the design without the built-in option requires a reduced CAPEX, but a higher investment at the time of the highway elevation since a demolition of the rigid viaduct and construction of a new viaduct are needed to adapt to an elevation of the adjacent segments of the highway (Figure 4.3).

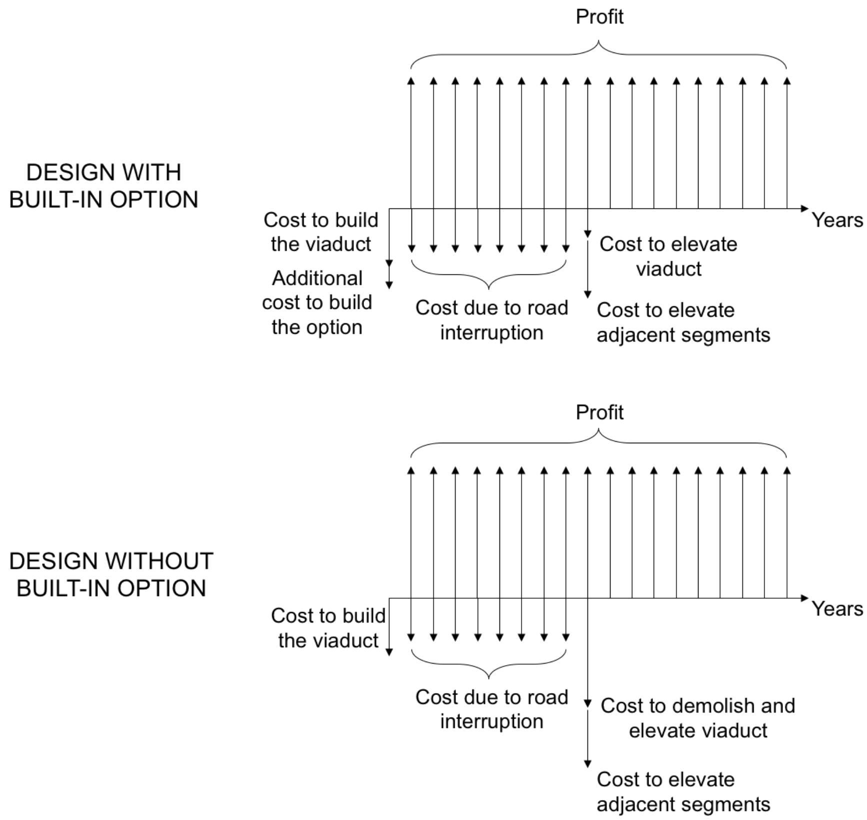



**Figure 4.3: Cash flow analysis for the two design alternatives**

The NPV of each design alternative, and consequently the differences between their NPVs vary according to when the LA will elevate the adjacent segments of the highway. The more the LA delays the elevation of the highway, the less attractive the option to elevate the deck at a low cost becomes. This happens since the additional cost to demolish and build a new viaduct becomes less and less significant in present value terms as the time horizon increases. Conversely, if the LA expects to raise the highway in the short-term, the savings from not having to demolish and build a new viaduct easily outweigh the additional upfront cost that needs to be incurred to build in the option to elevate the deck.

The date as to when the LA may elevate the highway in the future is, however, unknown. To assess the net option value, we just need to subtract the present value of the costs of one design solution from those for the other solutions, assuming different dates for elevating the highway. For the sake of computation of the costs, a ten year interval - 0, 10, 20… 110, 120 years, and never - was selected which produces results with a satisfactory precision[9]. The option net value for different dates as to when the highway gets elevated can then be easily obtained using equation 4.4. Table 4.2 shows the present value of the costs[10] for the two design solutions for different dates of 'highway elevation' and the difference between the two, i.e., the option net value.

**Table 4.2: Present value of the costs of the two design alternatives (with and without option built-in) and option payoff (£M)**

| Year of highway elevation | Present value of $C_t$ with option | Present value of $C_t$ without option | Option Net Value ($C_t$ w/ option – $C_t$ wo/ option) |
|---|---|---|---|
| 0 | -7.85 | -10.37 | 2.52 |
| 10 | -21.71 | -23.47 | 1.76 |
| 20 | -33.59 | -34.82 | 1.23 |
| 30 | -42.48 | -43.31 | 0.83 |
| 40 | -49.13 | -49.66 | 0.53 |
| 50 | -54.11 | -54.42 | 0.31 |
| 60 | -57.83 | -57.98 | 0.14 |
| 70 | -60.62 | -60.64 | 0.02 |
| 80 | -62.71 | -62.63 | -0.07 |
| 90 | -64.27 | -64.13 | -0.14 |
| 100 | -65.44 | -65.24 | -0.19 |
| 110 | -66.31 | -66.08 | -0.23 |
| 120 | -66.97 | -66.70 | -0.26 |
| Never | -66.89 | -66.54 | -0.35 |
| | | **Average ONV** | **0.43** |

[9] Although the date of highway elevation is a continuous event, assuming its occurrence in discrete intervals of ten years allows identifying the trend of the option value with reasonable precision.

[10] These costs exclude the costs of highway interruption. As mentioned previously, the latter are irrelevant to compare the option value as they are exactly the same for both alternatives.

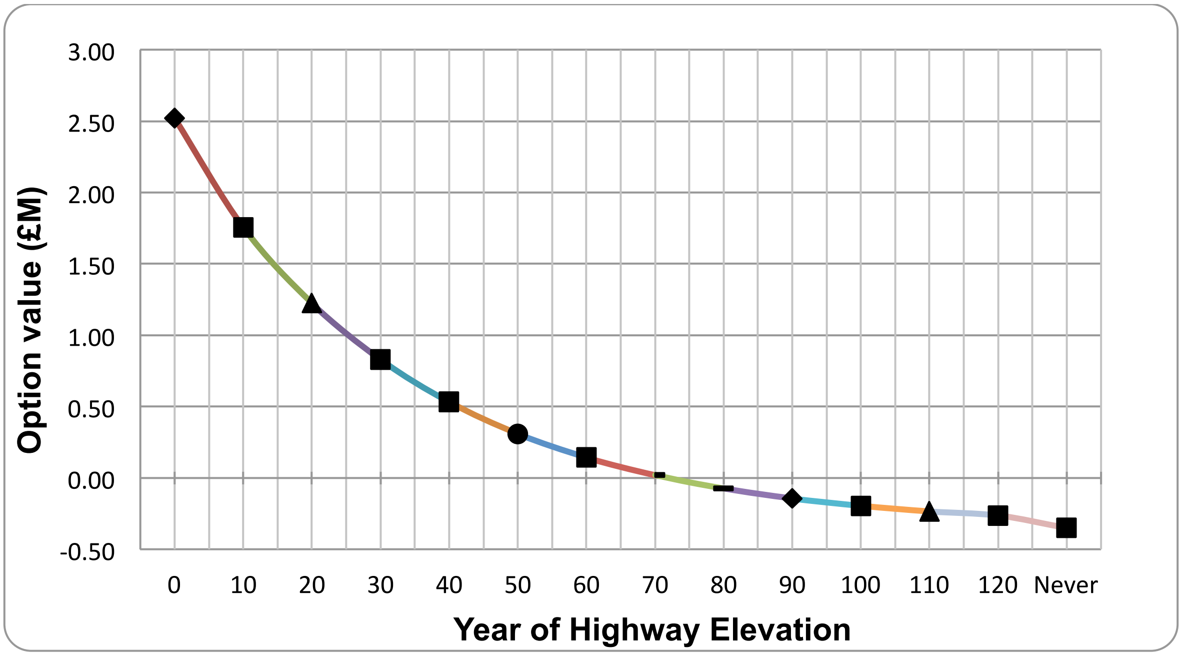



**Figure 4.4: Option value for different dates of highway elevation**

Table 4.2 shows that in year 0, a quite unrealistic scenario but useful for testing the robustness of the model logic, the present value of the costs of the design with the built-in option is (-)£7.85M. It consists of the cost to build the viaduct (£3.15M), the costs to build in the option (£0.35M), the costs to elevate the deck (£0.5M), and the costs to elevate the adjacent highway segments in that year (£3.85M). The present value of costs of the alternative solution without the option built-in is (-)£10.37M. It consists of the cost to build the viaduct (£3.15M) and the costs to demolish and build a new viaduct at a higher elevation (£3.37M) as well as elevate the adjacent highway segments in that year (£3.85M). The option net value is obtained from the difference between the present value of the cost of the alternative with option and the alternative without the option, i.e., £2.52M in year 0. Figure 4.4 shows the option value plotted for different dates of highway elevation. Table 4.2 also shows a first crude approximation for the average option net value: £0.43M. It was estimated by considering that the elevation of the highway had the same chance of occurrence in each one of those scenarios, an assumption that merits further refinement. The final option net value (FONV) can be obtained by:

$$FONV = \frac{\sum ONV}{numberofscenarios} \quad (4.5)$$

Although relatively straightforward to calculate, the analysis of the option net value fails to properly account for the flexibility inherent to capital investment decisions, and particularly for the flexibility in exercising the option to elevate the highway in the future. To account for the uncertainty around when to elevate the highway, I calculate various NPVs, one for each specific date as to when the deck would be elevated over the operating lifetime of the viaduct based on a speculation about future states of the world. As a result, using average values to estimate future outcomes is inaccurate at best and misleading at worst (Neufville, 2008). For that reason, the next section calculates the net option value using a real options analysis, which allows postponing decisions until uncertainties get resolved as well as working with a broader range of values instead of best estimates.

### 4.5.3 Real Options Analysis

The net value of the option to elevate the deck in future is a function of the estimated option value as well as of the cost to build in the provisions that enable to elevate the deck in the future at a reasonable cost. Put differently, the option net value (ONV) is the option value (OV) discounted by the cost of building in the option (OC):

$$ONV = OV - OC \quad (4.6)$$

Since the cost of building in the option was assumed previously to be £0.35M, the option net value (ONV) can be easily obtained by calculating the option value (OV). Conceptually, the built-in option to elevate the deck of the Upton-upon-Severn viaduct in the future can be framed as a switch option (Smit & Trigeorgis, 2004). The LA can exercise this option and elevate the deck and the adjacent highway segments if the socio-economic costs from sporadic road interruptions become problematic. This framing of the decision-making process lends itself to be modelled by a binomial lattice valuation, which replicates the characteristics of the process by estimating a range of outcomes that could develop from a starting point (Cox et al., 1979). These models can be built without using very complex math, they can be more easily customised, and they are relatively transparent and flexible (Copeland & Tufano, 2004).

Specifically, the binomial lattice approach requires: (1) figuring out the range of possible values of the underlying asset, assuming that these values will range at a constant volatility; and (2) working back (from the expiration date) the value of the option at the various points where a decision to switch can be made during the asset operating lifecycle. The use of a 'random walk' on a regular lattice (Cox et al., 1979) to model possible variations in the value of the asset in a complex system is justified on the basis that this process arguably can be assumed to vary along a steady long-term trend in the same way that prices for stocks and other publicly traded assets evolve. The binomial method assumes that the value of the underlying asset will fluctuate randomly through time with a constant volatility and can be formally described by the random walk theory of the GBM. Admittedly, there are instances in which the modelled variables do not follow a stochastic process similar to the GBM. However, this is not the case in the investment analysis of the viaduct. Potential overestimations in the option value due to the overestimation of the uncertainty when using GBM are unlikely to significantly change the results in this kind of analysis (Metcalf & Hassett, 1995).

The mechanics of the binomial lattice valuation that represent this fluctuation are quite straightforward (Luenberger, 1998). First, the range of the possible economic costs associated with the closure of the highway needs to be estimated. Starting at the current time with a cost $C_0$ and dividing time in small increments $\Delta t$, the cost will increase in the next time increment by a factor $u$ to become $C_u=uC_0$. Or alternatively, it will decrease by a factor $d$ to become $C_d=dC_0$. The probability of $C_0$ performing an upward movement to become $C_u$ is $p$ and the probability of $C_0$ performing a downward movement to become $C_d$ is $1-p$. The variables $u$, $d$ and $p$ can be calculated as follows:

$$u = e^{\sigma\sqrt{\Delta t}} \quad (4.7)$$

$$d = e^{-\sigma\sqrt{\Delta t}} = \frac{1}{u} \quad (4.8)$$

$$p = \frac{(1+r)-d}{u-d} \quad (4.9)$$

where *σ* represents the constant volatility in the costs through time, and *r* represents the risk-free rate of return (time value of money). This can be repeated for as many time increments as chosen. Figure 4.5 shows the representation of the binomial step for multi-period options.

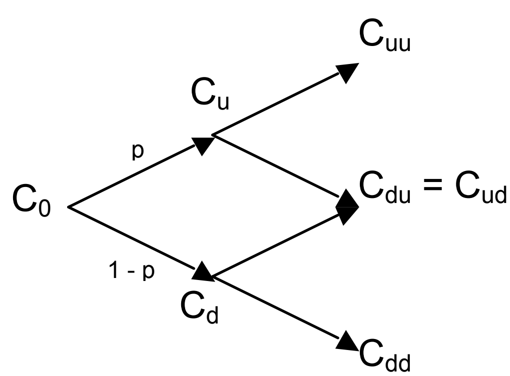



**Figure 4.5: Event tree representation for costs that follow a normal random walk**

As discussed previously (section 4.5.1), an indicative value of the total annual average costs due to closures of the highway when t=0 are £1.63M. Based on historical data of flood events (1988-2002), the volatility in the number of days of road closure was estimated at 48.12%[11]. Based on this volatility and assuming the risk-free interest rate to be 0.05%[12], in the next time increment the total cost of highway closures can increase by a factor u=4.58 to become Cu=£7.46M, or

[11] Appendix D explains how the volatility in the number of days of road closure was obtained from historical data.

[12] The 4-month U.S. Treasure bill is often used as the risk-free rate. Retrieved from http://www.treasurydirect.gov.

decrease by a factor d=0.22 to become Cd=£0.36M. Based on the fluctuation of this variable, the event tree for the costs can be plotted. This variable is capped (£39.18M), since the number of interruptions per year cannot be theoretically higher than 365 days. Figure 4.6 shows the event tree representation for the costs.

| Year | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ct (£M) | 1.63 | 7.46 | 34.17 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 |
| | | 0.36 | 1.63 | 7.46 | 34.17 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 |
| | | | 0.08 | 0.36 | 1.63 | 7.46 | 34.17 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 | 39.18 |
| | | | | 0.02 | 0.08 | 0.36 | 1.63 | 7.46 | 34.17 | 39.18 | 39.18 | 39.18 | 39.18 |
| | | | | | 0.00 | 0.02 | 0.08 | 0.36 | 1.63 | 7.46 | 34.17 | 39.18 | 39.18 |
| | | | | | | 0.00 | 0.00 | 0.02 | 0.08 | 0.36 | 1.63 | 7.46 | 34.17 |
| | | | | | | | 0.00 | 0.00 | 0.00 | 0.02 | 0.08 | 0.36 | 1.63 |
| | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.08 |
| | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | 0.00 | 0.00 |
| | | | | | | | | | | | | | 0.00 |

**Figure 4.6: Event tree representation for costs of highway closures modelled as following a normal random walk**

After modelling the possible fluctuation of the costs of highway closure, the payoff of having an option to switch can be found. The payoff *P* at each end node is the maximum between the savings obtained with not interrupting the traffic ($C_t$) discounted by the cost that needs to be incurred to exercise the option to elevate the highway ($C_{exe}$) and 0[13]. This means that if the floods become a major socio-economic problem, exercising the option to elevate the highway brings massive savings. If the option to elevate the deck has been built in the design of the viaduct,

[13] It is assumed that the payoff cannot be negative as an investor would never exercise the option if the exercise costs are higher than the savings obtained with not interrupting the traffic. This assumption might not hold in some circumstances, and the decision to exercise the option might be triggered by other factors. This limitation in the modelling is discussed later in this chapter.

the LA can elevate the adjacent segments of the highway without also having to demolish and build a new viaduct once the segments of the new highway are elevated. It is assumed that an eventual construction of a new highway at a higher elevation would use the same alignment as opposed to involve construction of a new highway and viaduct at a different location. Conversely, if the socio-economic costs of extreme flood events remain manageable, the savings obtained from elevating the highway and raising the deck of the viaduct remain relatively small. Investors will presumably decide as to whether switch the operating regime, i.e., elevate the highway and the deck of the viaduct keeping the same alignment whenever these savings ($C_t$) are higher than the cost to exercise the option ($C_{exe}$). The payoffs at each node are represented in Figure 4.7. These values are obtained with the following formula:

$$P = MAX\left[C - C_{exe}, 0\right] \tag{4.10}$$

| Year | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P(£M) | 1.13 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | 0.00 | 1.13 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | | 0.00 | 0.00 | 1.13 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | | | 0.00 | 0.00 | 0.00 | 1.13 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 1.13 | 6.96 | 33.67 | 38.68 | 38.68 |
| | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.13 | 6.96 | 33.67 |
| | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.13 |
| | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | 0.00 | 0.00 |
| | | | | | | | | | | | | | 0.00 |

**Figure 4.7: Payoff (£M) at each node**

With the payoff of having an option to switch known, it is possible to estimate the option value at the previous node. The option value (O) at the any end node can be expressed by:

$$O = \frac{1}{(1+r)}\left[p * P_u + (1-p) * P_d\right] \quad (4.11)$$

where $P_u$ is the upside payoff and $P_d$ is downside payoff at the subsequent time increment.

Since this is an American option, i.e., it can be exercised at any time before the expiration date, the actual option value at each node is the maximum between the option value and the payoff. For example, consider the seventh entry on the last column (110 years) in Figure 4.8. The option value there is (1/1.005) x [0.18 x 1.13 + (1 – 0.18) x 0] = 0.20. Since the option value is higher than the payoff at the same node (0.00), the option value is what is entered in the value lattice. Working back from the payoff at the expiration date, it is then possible to arrive at the value of having the opportunity to switch. The option value when $t=0$ is £1.25M. Finally, discounting the capital cost to build in the option (£0.35M), the net option value can be determined: £0.90M. The option value obtained with the real option analysis (£0.90M) is much higher than the value based on the difference between the two NPVs (£0.31M). This is expected as it properly accounts for the flexibility in exercising the option to elevate the highway in the future.

| Year | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OV (£M) | 1.25 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | 0.20 | 1.25 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | | 0.00 | 0.20 | 1.25 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 | 38.68 | 38.68 |
| | | | | 0.00 | 0.00 | 0.20 | 1.25 | 6.96 | 33.67 | 38.68 | 38.68 | 38.68 |
| | | | | | 0.00 | 0.00 | 0.00 | 0.20 | 1.25 | 6.96 | 33.67 | 38.68 |
| | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 1.25 | 6.96 |
| | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 |
| | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | 0.00 | 0.00 |
| | | | | | | | | | | | | 0.00 |

**Figure 4.8: Options values working back through the lattice**

## 4.6 Final Observations

The insights yielded by the mathematical modelling of the value of a built-in option to elevate the deck of the Upton-upon-Severn viaduct in the future confirm the intuition behind the design decision endorsed by the LA based on the technical advice of the design consultant. Both analytical assessments, first using a rudimentary cost-benefit analysis and subsequently using a real options pricing model, consistently show that building the switch option pays off. However, the real options modelling points to a higher value of the option as it accounts for flexibility as to when the option is exercised and makes this decision contingent on the pay off of doing so. This consistency in results supports the strategic design decision. The fact that the cost to design the option was low relatively to the intuitive value of the option seems to have considerably influenced the intuitive rationale.

Recognizably, the formal analysis of the Upton-upon-Severn viaduct with the cost-benefit or binomial approach required a large number of logic and numeric assumptions. For instance, modelling the case as a switch option assumed that at some point costs could accumulate and generate negative payoffs that would trigger the decision to exercise the option. Not necessarily the decision to elevate the highway (if the LA ever decides to do it) will be linked to the projected payoffs. Socio-political factors and other institutional issues, e.g., funding opportunities, budget surplus, will also inform this decision. Modelling other factors that can affect the value of the option would, as expected, further complicate the mathematical representation of the problem. Moreover, the analysis of the case did not investigate thoroughly what the most accurate numeric values of the input variables ought to be. This exploratory case was intended to explore how formal methods could be applied to assess the option value, and to learn about what the major hurdles associated with practical applications of the methods. A more meticulous assessment of the numerical values for the input variables, and developing of more accurate models would require many additional hours and would significantly add costs to the model development process.

Importantly, the analytical assessment of the focal problem in the case was complex and time-consuming despite the stylised mathematical models that were used. Finding an acceptable analytical representation for the problem and suitable numerical values for the different variables was not trivial, and sensitivity analysis ought to be performed to test the robustness of the results to variance in some of the numerical assumptions or logical relationships. Put differently, the insights corroborate intuitive thinking, but the analytical modelling of the problem turned out to be a laborious process. Furthermore, the end product cannot be directly applied to other design problems. As a result, persuading a sponsoring organization, the project client, to make an investment in real options pricing models for relatively mundane design problems is challenging, particularly if it operates under a tight budget. It is also unlikely that the design consultant, invariably operating on tight margins, would be willing to bear the costs.

Indeed, the adoption of options logic by the design consultant to assess the value building a flexible design for the Upton-upon-Severn viaduct did not involve any formal analytical work. The urgency to replace the deteriorated viaduct and issues of affordability ruled out elevating the highway in the short-term. The marginal costs to build in the deck-elevation option and the flexibility offered by this concept in turn formed a proposition compelling enough for the LA to endorse this alternative. Framed by the design consultant as a fairly mundane design problem, any attempt to analytically model this problem would be perceived as overkill. The firm appointed as design consultant itself did not have the technical expertise to do it. This does not mean however that the analytical model did not add value. On the contrary, the analytical work proved very useful to sharpen thinking and build confidence on intuition. It helped to develop a rigorous logic to shed light on the critical variables and assumptions that should inform the framing of decisions on design for evolvability architecture, and how these variables relate to one another. The analysis also showed that the real options theory provides a structured lexicon useful to both refine the articulation of the design problem, as well as to assess and compare the value of alternative design solutions under conditions of foreseeable uncertainty.

Taken together, the findings from the qualitative and analytical studies yield important insights. They suggest that real options pricing methods may be inadequate to support mundane design for evolvability at the front-end of capital projects. It is reasonable to conjecture that if the application of these methods was not trivial for a simple design problem involving a single option, their application can be overwhelming once the number of options to design increases, especially if these options are related to one another. However, the findings suggest that the theory underscoring real options modelling can still be of much use. Qualitative real options reasoning can help project teams discuss the trade-offs between design alternatives and make sensible and informed decisions at the project front-end under conditions of uncertainty in requirements.

All in all, these findings are aligned with systematic claims in the literature (Bowman & Moskowitz, 2001; Kalligeros, 2006; Lander & Pinches, 1998) that real options pricing models can be hard to apply to real-world problems in a tractable way and they pose challenges in terms of attempting to numerically estimate the input parameters. Crucially, this exploratory study did not address the question of *who* pays for the flexibility built-in upfront. Here, this was a lesser issue. The institutional context was characterised by a single funder, and the cost to build in the option was marginal relative to the overall capital investment. This may not necessarily be the case however in more complex institutional environments wherein multiple project stakeholders have to multilaterally agree on a project design concept, including any design for evolvability provisions. This problem is compounded by the fact that these multiple stakeholders, who often have conflicting interests, also have to multilaterally agree on a funding strategy for the design concept. This is the focal problem explored empirically in the next chapter.

# 5 Design for evolvability in multi-funder environments: insights from an embedded case study at Network Rail

This chapter consolidates the analysis of the empirical findings from an embedded case study on front-end strategizing practices in capital projects with multiple funders. Unlike the Upton-upon-Severn Viaduct case study, wherein the local authority was the only funder, more often than not multiple organisations are involved in project funding. Under such conditions, these funders and other organisations with legitimate stakes over the project outcome – e.g., local authorities with planning power over the land – need to collate their views of the world into a vision for the project at the front-end strategizing. This is invariably a challenging process as the different funders and other legitimate stakeholders may operate with quite different planning horizons and fundamentally different strategic visions for the project.

To further the understanding of design for evolvability practices in capital projects with multiple funders this doctoral research undertook an embedded case study on Network Rail (NR), the owner and operator of the railway infrastructure in Great Britain. Specifically, it investigated the front-end strategizing practices within NR's capital projects division, and probed deeply into the implementation of those practices across a sample of three railway capital projects. These projects varied, first, in terms of the scope of the project: from the £12M Salford Crescent Station project aimed at redeveloping a 1980s station that was dangerously overcrowded at peak times to the £150M project to modernize the Reading station, one of the UK's most important and busiest stations outside London. Second, the sample selected varied in the number of organisations directly involved in front-end strategizing: from almost a dyadic relationship in the case of the Arpley Chord project between NR and Warrington Borough Council to multiple and complex relationships between a multitude of stakeholders, as was the case in the Salford Crescent project.

This chapter will begin with a general description of the institutional structure of NR and the main processes governing the development of its capital projects. The subsequent sections provide an in-depth description of the three capital projects selected as sample case studies. The unit of analysis is the design for evolvability (i.e. future-proofing) practices. The findings of a comparative analysis of the design for evolvability practices, at the front-end strategizing stages for the three projects, will thus be presented in the final section of the chapter.

## 5.1 Network Rail

The British railway system was created by private companies in the $19^{th}$ century, however it was nationalised under the Transport Act 1947 and became British Rail until the mid-1990s. In 1994 the British rail industry was reprivatised and Railtrack took control of Britain’s rail infrastructure. The privatisation turned out to be very difficult to implement effectively. The life of Railtrack itself was bedevilled with a number of disastrous capital projects such as the fiasco to upgrade the West Coast main line in 1999, when Railtrack announced previous estimates would more than double. Railtrack also suffered with a number of fatal accidents such as the Southall crash in 1997 and the Ladbroke Grove crash in 1999. These failures were in part attributed to an institutional system which made it hard to align the competing public interests with those of the company’s shareholders. After an investigation of the Hatfield crash in 2000 revealed that inadequate maintenance of the rails was behind the accident, the collapse of Railtrack became inevitable. In 2001, the Government decided to replace the unsuccessful privately-owned company Railtrack with NR. From a legal and financial point of view, the infrastructure provider became a company limited by guarantee and a private organisation operating as a commercial business. NR did not have share capital or shareholders, but it had members. These members did not have any financial or economic interest in the company, which meant that they did not receive dividends, share capital, or any other form of payment from NR. As a ‘not-for-dividend’ company, all NR profits were expected to go straight back for re-investment into the rail network.

At present, NR is a large organisation with circa 35,000 employees and its operations are intertwined with the activities of many public and private organisations. The company owns, operates, maintains, and develops the main rail network in Great Britain. This includes around 20,000 miles of tracks, 40,000 bridges, tunnels and viaducts, 6,650 level crossings, and 2,500 stations that are mainly leased to private train operating companies[14]. NR does not itself run passenger or freight services. It shares the responsibilities of providing a safe, reliable and efficient railway with other companies. This includes, but is not limited to train operating companies (TOC) and freight operating companies (FOC). TOCs and FOCs are considered to be institutional clients of NR from a transactional perspective. It also involves the Office of Rail Regulation (ORR), an independent institution responsible for regulating safety and economic issues of Britain's railways, and funding bodies such as the Department for Transport (DfT).

NR is mainly funded by multi-billion pound annual government grants and income from track access charges – either rail fares or revenue support payments from the government. It can also borrow money which the government guarantees. This income is essential to pay for its capital investment programme to improve the railway service. For financial and planning purposes, NR works within 5-year "Control Periods". For the Control Period 4 (CP4), running from 2009/10 to 13/14, the company estimated an overall expenditure of £34 billion. Approximately 60% of the funding for CP4 has direct or indirect public support.

As with most capital enterprises, NR has formalised its capital development process into a sequence of stages and deliverables. The Governance for Railway Investment Projects (GRIP)[15] outlines the NR lifecycle approach for developing and managing capital projects. It details the project deliverables and the stages in the project when they need to be delivered. The GRIP process consists of eight stages

---

[14] NR owns and operates 18 of the larger stations; the remaining stations, whilst mostly owned by NR, are operated by other railway bodies, usually franchised passenger railway undertakings, such as Arriva Trains Wales and Northern Rail.

[15] Formally known as the “Guide to Railway Investment Projects”.

in addition to the pre- and post- GRIP stages. Table 5.1 details the main activities of each stage.

**Table 5.1: NR Development Process for Capital Projects (GRIP)**

| Stage | GRIP | Activities |
|---|---|---|
| # | Pre-GRIP | Initial planning and preparation to validate the project |
| 1 | Output Definition | Identify what the outputs will be and how they may be achieved |
| 2 | Pre-Feasibility | Detail the strategy of how to deliver the project outputs |
| 3 | Select Concept | Examine different alternatives and select a single one to be developed |
| 4 | Develop Concept | Develop a single concept at a high level and initiate tendering process |
| 5 | Detail Design | Award contracts and develop detailed design and implementation plan |
| 6 | Construct, Test, and Commission | Carry on physical works, ending with completion/commissioning |
| 7 | Scheme Hand Back | Hand back the asset to the asset owner, operator, or maintainer |
| 8 | Project Closeout | Finalise and archive project documentation; capture lessons learned |
| # | Post-GRIP | Demonstrate that the project has delivered its benefits |

The GRIP stages are expected to vary in length and rigour depending on the project type and complexity. Pre- and post- GRIP stages, for instance, only have to be undertaken for the more complex projects. The findings suggest in particular that the post-GRIP stage is rarely undertaken, as one NR project sponsor – a role within the capital projects division acting at the interface of the negotiations between NR and the external stakeholders – explained:

> “I‘ve never had any experience with post-GRIP; once project managers have gone through the Project Closeout, it doesn’t make much sense to go through an additional stage. I don’t know what the purpose of this stage is”.

Each GRIP stage is designed to produce a specified set of deliverables. Examples of these deliverables are: project management plan, risk management plan, risk registers, and value management report. The majority of these deliverables are modified and updated over the GRIP stages. An example is the project remit, a document that outlines the main requirements of the project. During the pre-GRIP stage, the project team is responsible for putting together a business case. Subsequently, the sponsor’s remit – produced by the commercial sponsor based on the business case – has to be delivered at the first stage of the GRIP process. The project manager has, then, to discuss it with the commercial sponsor in order to develop the project manager's remit. This document will guide the team assigned to the project from stage 2 onwards. Finally, the project manager's remit can be updated as the remaining stages of the project unfold in light of the new information.

To further investigate the nature of design decision-making at NR project front-end strategizing, a diverse sample of capital projects was built by varying the overall project scope and the complexity of the institutional environment from a stakeholder perspective. Three projects were chosen in order to build a diverse sample: the £15M Arpley Chord enhancement project, the £150M Reading Station redevelopment project, and the £12M Salford Crescent Station redevelopment project. The unit of analysis are the design for evolvability practices at the front-end strategizing for these capital projects. The next section describes these three projects in detail whilst the subsequent sections provide a comparative analysis of the upfront design for evolvability practices.

## 5.2 The NR capital project context

### 5.2.1 Arpley Chord enhancement project

The scope of this project consisted of installing a new chord line to connect the Arpley Branch lines to the Ditton Goods lines (Figure 5.1). From a pure railway perspective, the new chord would improve working conditions and eliminate inefficient run-round and turn-back manoeuvres, which would allow the freight operators to save approximately 30 minutes of journey time. Because the scheme would have positive impacts mainly to freight operations, NR deemed this scheme was not a priority for its capital projects division. However, this scheme was an important one for spurring the socio-economic development of Warrington, a town in the North West of England with approximately 200,000 inhabitants. The construction of the new chord would enable the closure and demolition of the old

Arpley Junction as well as of the associated sidings. Once these old assets were out of the way, the Warrington waterfront would become a lot more accessible to the Warrington inhabitants and people working in the city centre. This was aligned with Warrington Borough Council plans to regenerate the area over the next years. The council's vision for Warrington was for it to be 'recognised as one of the best places to live and work in the UK, where everyone enjoys an outstanding quality of life by 2030'. The actual speed at which the regeneration of the area would occur was however naturally contingent on other factors, notably the health of the national economy and Warrington's development as a regional growth point.

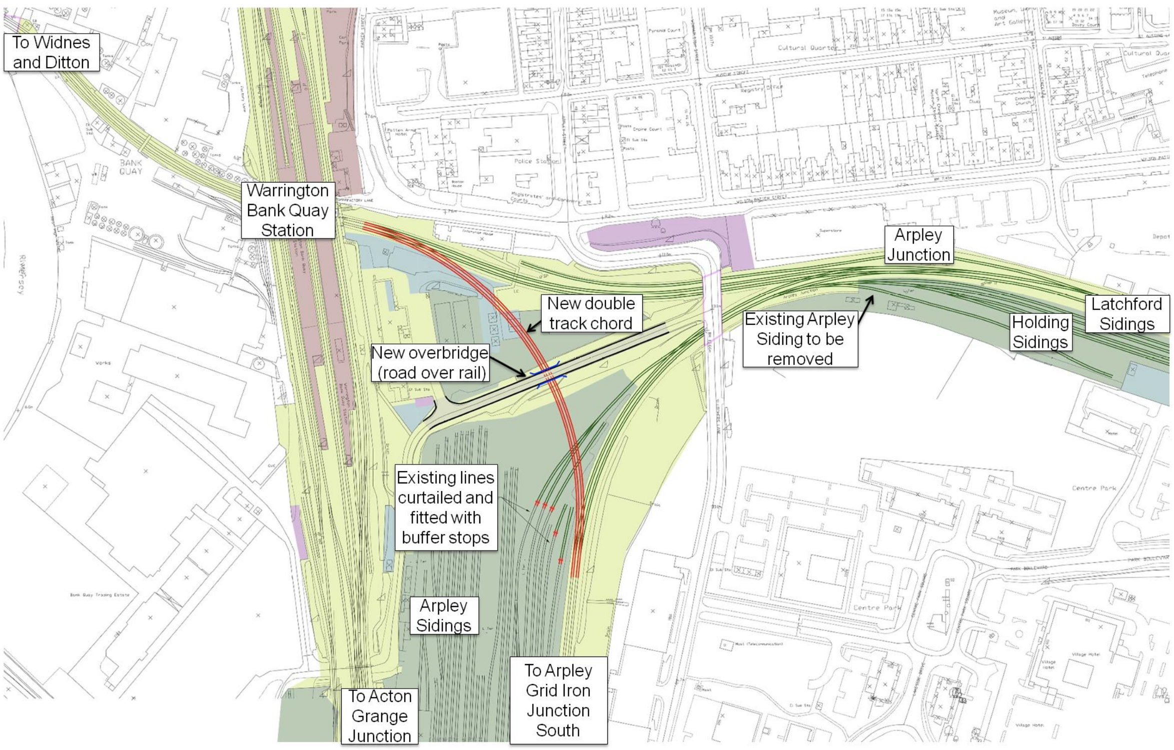



**Figure 5.1: Layout drawings of the Arpley Chord Infrastructure project (source: NR's Project Remit for Arpley Chord)**

NR's capital project division had estimated this project to cost £15M. It also framed it as a third-party project, which meant NR expected the project to be funded by the Warrington Borough Council. Put differently, NR framed itself as a project supplier and the Council as the project client. After almost 20 years lobbying for the project, in 2009 the Council finally managed to secure £27,000 of financial support for the first two GRIP stages[16] from a regional development agency, the North West Development Agency (NWDA). The overall institutional context started to change dramatically with the financial crisis that had major repercussions on the UK economy in 2008. The chances of re-electing the centre-left party in the national elections started to falter. Local officials quickly realised that if the political power shifted to the right, after the elections of 2010, the NWDA would likely be abolished as that had been one of the pledges of the Conservative party in their manifesto. This meant the Council were under considerable time pressures to secure funding for the project. A document produced by an investment panel from NR emphasized the possibility of the Council losing grant funding from the NWDA for development and recommended the utilization of the available funding within the 2009/10 fiscal year[17]. The construction and implementation period would take around nine months. Interestingly, the elapsed project lifecycle was expected to last 5 years from the Pre-GRIP phase, initiated in 2008, to the GRIP 8 Project Closeout scheduled to finish in 2014, the last year of the Control Period 4 for NR. Considering that the estimated project costs were under £50M and the implementation period was inferior to two years, Arpley Chord was characterised as a medium complex project in the world of NR.

To cope with future requirements, the NR capital projects team believed that the design should incorporate two main 'future-proof' provisions. These provisions had to also be met in order for the project to comply with the internal NR standards. First, the design of the scheme should leave open the option to electrify the line in the future and therefore allow enough free space for installing the Overhead Line Equipment (OLE). The electrification of the railway network was a key strategic aim for NR. Electrification reduces $CO_2$ emissions and noise pollution, and it also improves air quality. Electric trains, on average, emit 20 to 30 percent less carbon

[16] The first two stages are less capital intensive as they only involve output definition and pre-feasibility. Both phases require relatively low capital expenditures when compared with the subsequent phases, especially construction and implementation phase.

[17] The new coalition government indeed abolished the regional development agency in 2010.

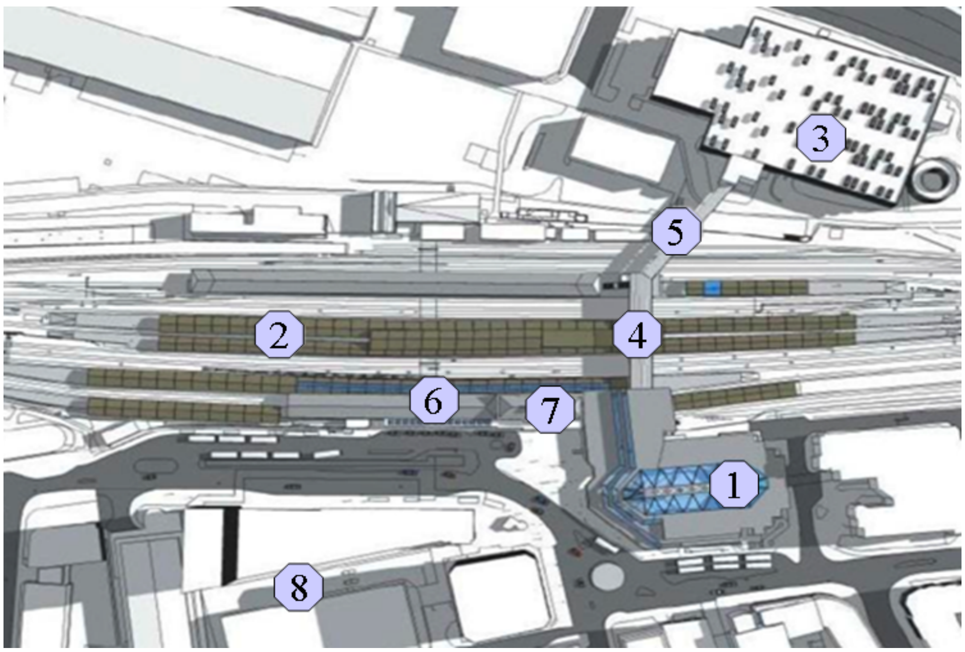
dioxide than diesel trains. Their superior performance in terms of braking and accelerating can help reduce journey times and increase levels of train reliability and availability, as well as lowering operating costs. Electric trains also provide more seats than diesel trains due to greater space afforded by a more compact engine compartment, therefore increasing passenger capacity for railway transportation. In addition, the NR team also believed that the design should leave open the option to increase the height, length or width of a train car that can travel on the network in the future. To leave this option open, the NR team advocated designing and building the Arpley Chord so as to cater for the largest gauging[18] (W12). This meant that the design of the tracks should ensure minimal lateral clearance necessary for the construction of embankments that would need to support the potential additional loads and minimize potential side-wear risks. The two provisions were interrelated as the investment to provide gauge clearance, the NR team reckoned, would also contribute to leave enough space available for future electrification of the railway. The team estimated that these provisions could increase the cost in track development up to 50%. Since the original budget allocated approximately £1M for the track development, £500,000 would be additionally needed to allow for increasing the capacity of the railway in the future. For NR, the business case for investing in these provisions was crystal clear. The Council, however, understood the provisions were necessary to safeguard an economical modernisation of the freight line in the future. It was debatable whether the Council should incur the upfront costs to future-proof the line, as discussed in section 5.3 later in this chapter.

### 5.2.2 Reading Station redevelopment project

The Reading Railway Station was first opened to public in 1840, and it has been growing in capacity ever since. During the 20th century, Reading became one of

[18] The rail gauge is the distance between the inner sides of the heads of the two load bearing rails. The loading gauge defines the maximum height and width for railway vehicles and their loads. NR uses a W loading gauge classification system that ranges from W6a (smallest) to W12 (largest).

the busiest railway stations in the country, outside London. With around 17 million users annually, it is currently used as both an important hub station catering for passengers interchanging between services and as an origin and destination for journeys. The various enhancements, in response to increasing demand over the years, led to the incorporation of a number of facilities within the station. A concourse at the south-east of the station, 10 train platforms, a station multi-storey car park, a passenger overbridge linking the concourse to the platforms, another overbridge linking the passenger overbridge to the car park, and a Western Gateline to provide an alternative entrance to the station (Figure 5.2).




1- Concourse at the south-east of the station
2- Ten train platforms
3- Multi-storey car park
4 Passenger overbridge linking the concourse to the platforms
5- Overbridge linking the passenger overbridge to the car park
6- Western Gateline for alternative entrance to the station
7- Guineas Public House (Grade II Listed Heritage Building)
8- Station Hill Development area

**Figure 5.2: Existing station layout (source: NR’s Project Remit for Reading)**

Despite all the improvements to the station in recent years, the Reading Station has become a major bottleneck on the Great Western Main Line (GWML)[19] that causes systematic delays and prevents operating companies to add more and longer trains to the services they provide. By the end of the 20th century, the Reading station was known for exhibiting sub-optimal platform and track layouts, both of which were leading to poor operational flexibility for passengers and freight train operators. In the financial year 2005/06, these characteristics were already causing NR, its owner, to pay over £13 million to First Great Western (FGW)[20], the station operator, due to reactionary delays[21]. Due to the existing layout and capacity for the Reading Station, NR and FGW struggled to increase the number of services running through the station. Both parties acknowledged that significant investments were needed to deal with the capacity constraints at Reading, and to bring services back to satisfactory levels. The plans to redevelop the Reading Station finally gained traction in 2006, as Ian Coucher, the NR's Chief Executive at the time, explained the rationale for the capital investment:

> "More passengers are choosing to travel by rail than ever before and, to cater for this success, we need to increase capacity across the railway. This investment in Reading is one of the most important planned for the whole country and will deliver a huge improvement for passengers both locally and nationally."

In 2007, the Department for Transport (DfT) announced that it was awarding NR a £425 million project grant aimed at increasing the railway capacity at Reading. This was a significant contribution towards the anticipated final cost of the project, which

---

[19] The Great Western Main Line is a principal artery in the UK railway network, running westwards from London Paddington station to the west of England and South Wales.

[20] First Greater Western is a train operating company owned by First Group that serves Greater London, the South East, South West and West Midlands regions of England, and South Wales.

[21] A Primary Delay is a delay to a train that results from an incident that directly delays the train concerned, irrespective of whether the train concerned was running to its schedule at the time the incident occurred. A Reactionary Delay is a delay to a train that results from an incident that indirectly delays the train concerned, i.e., the delay is the result of a prior delay to the same or any other train.

NR estimated to be £849 million (2007 Prices). The project funding was almost entirely obtained through NR's capital projects list for the Control Period 4 (£629.8M). However, due to the long duration of the project, part of the funding would be obtained and utilized during Control Periods 3 (£32.5M) and 5 (£186.7M). Apart from the £425M already awarded in 2007, DfT was also expected to fund the remaining capital necessary for the project in the subsequent years. The funding plan was stated in the Transport and Works Act Order[22], which indicated that the project would be fully funded in the coming Control Periods (CP4 and CP5), provided it still delivered the agreed outputs.

The aim for this multi-million pound project was to deliver increased passenger capacity and ease the pedestrian flow at the Reading station. The key elements of the project scope included the modernization of the railway infrastructure near Reading, and the redevelopment of the station. In terms of the railway infrastructure, the scheme main items included the development of grade separation of the main lines at the west end of Reading Station, i.e. a new flyover that would allow express trains to travel on fast lines up and over slower lines. This was to prevent conflicts and delays and to allow more trains to run. It also included the installation of new signalling and track layout and the construction of a new train care depot for FGW to the north side of the tracks at the Reading triangle. The new depot would substitute the depot lost in the area occupied by the new western flyover. The redevelopment of the station in turn would cost approximately £150 million. The plans to redevelop the station included building five new platforms, lengthening three existing platforms, and allowing for a new entrance into the station from the north of Reading to improve access. The whole scheme was expected to deliver a reduction in train delays in the Reading Station area by 37.7%, as well as to increase the overall through line capacity in the station by 75%.

---

[22] The Transport and Works Act Order is a system to authorize a new railway or tramway scheme in England and Wales by order of the Minister of State for Transport.

In 2008, Tata Consultancy team (formerly Corus Railway Infrastructure Services) was awarded the Reading Station Area Re-development design. Corus would be supported on the station design by various other suppliers such as Grimshaw Architects and Scott Wilson. Although NR commenced work in 2006 to establish and develop the infrastructure requirements for re-modelling the Reading station area, the actual construction, testing and commission phase, i.e. the GRIP stage 6, would only start by the end of 2010. In other words, the project team would only have a detailed design ready for construction after 4 years of discussions with several stakeholders. This was to identify (1) how to best represent costumer requirements, (2) what design solutions would best fulfil those requirements, and (3) how to develop the different design solutions to the point of engineering scope freeze and in sufficient detail to allow finalisation of the business case and scheduling of implementation resources. The key dates of the GRIP process are summarized in Table 5.2.

**Table 5.2: Key dates for each GRIP stage**

| GRIP Stage | | Start | Sign off |
|---|---|---|---|
| 1 | Output Definition | Feb 2006 | Jun 2006 |
| 2 | Pre-feasibility | Jun 2006 | Jan 2007 |
| 3 | Option Selection | Jan 2007 | Jan 2008 |
| 4 | Single Option Development | Jan 2008 | Oct 2009 |
| 5 | Detailed Design | Oct 2009 | Oct 2010 |
| 6 | Constructing, Testing, and Commissioning | Oct 2010 | Jul 2013 |
| 7 | Scheme Hand-back | Nov 2012 | Jul 2013 |
| 8 | Close-out | Jul 2013 | Mar 2015 |

Before starting the construction works to redevelop the station building, NR would need to submit a planning application to the local authority – the Reading Borough Council (RBC). The council was a key project stakeholder since it had the planning power and it was strongly influential in terms of securing support from other government institutions such as Government Office of the South East, South East of England Regional Assembly, South East of England Development Agency, and both Reading MPs. RBC aim in the redevelopment project for Reading Station was that it would succeed in transforming the station into a “World class 21st Century Station”. It has also identified the need to enhance the station in line with its aspirations for City Status, which meant that the station building needed to be connected with the plans for redeveloping the surrounding of the station and the River Thames area. At the same time as wanting a modern station, RBC was also keen on the preservation of the heritage status of the building. In 1976, Reading General Station was listed as Grade II in the statutory list of buildings of special architectural and historic interest, and special attention was needed to preserve this status.

To satisfy RBC, two main provisions should be designed in the planning application to ensure the station could economically accommodate future changes. First, a provision would be designed in to allow the further expansion of the newly developed concourse space. To this purpose, the design should account for the construction of a southern concourse located adjacent to the Western Gateline in the future. This expansion was necessary to ensure that the Reading Station could accommodate the anticipated growth in user demand over time without sacrificing the general quality of the concourse space that users would start enjoying right after the opening of the new concourse to the public. Therefore, the design of the entrance pavilion of the Western Gateline needed to allow for the possibility of being easily removed in the future when a southern concourse would be incorporated.

A second design provision involved building a piled wall separating the existing concourse from the area where the new concourse would be built. This piled wall would be designed with significant edge stiffening to allow the excavation of the road next to the Western Gateline without having to close the existing concourse or interrupt the operation of the escalators. Lowering the road level was essential to connect the station building to a £400M (2007 prices) commercial development adjacent to the station – the Station Hill Development – in the future. Sackville Properties bought the site for the Station Hill Development in 2005 and won planning approval in 2007. This development would cover an area of 5 acres and comprise 1.72 million sq ft of floor space to include space for offices, residential, and retail (cafes, restaurants, food outlets), an arts venue, a health and fitness facility, new public spaces, and a central public piazza. The council was interested in this development to transform the profile of Reading:

> "There is a clear commitment in the Reading 2020 vision for development in the study area that significantly raises the profile of Reading, from that of a much expanded, predominately Victorian, Thames Valley town to that of an internationally acclaimed and recognised city" [planning policy for the Station Hill Development]

In the aftermath of the 2008 financial crisis, however, progress on the Station Hill Development had been slow. Uncertainties over funding and the overall ill health of the UK economy had considerably delayed its development, and the date of when this project would finally get off the ground remained unclear. The project manager of Reading Station redevelopment commented on this issue in 2010:

> "They [Station Hill developers] have got a planning application for a development, which is five city blocks immediately across the road from the main station building, to redevelop that whole area. When we started our project, that redevelopment plan was prior to the financial problems we are currently in, and they were actually ahead. And the view was that we would be building the station building to catch up. We were kind of working with them, but now I don't know what's happening. That has completely stopped. There is still an application and I imagine at some point they will either sell it [land and planning rights] or they will get the money from other development. And because a lot of the buildings are completely dilapidated, there are real opportunities in that area."

The project manager's fears of an eventual reformulation of the business plans became a reality in the subsequent years. In 2011, Sackville Properties sold the land and planning rights of Station Hill Development to a joint venture between property investment fund Benson Elliot Capital Management and developer Stanhope plc. A year later, the new development team decided to remodel part of the plans and a new planning application was being prepared for submission by the end of 2012. NR, however, could not afford waiting for a new planning application to be submitted and approved for the private development and for all the uncertainties to get resolved. Delays in the station redevelopment project could potentially jeopardize future grant awards. The uncertainty around the development of the Station Hill, and the development of Reading more generally, created a major conundrum for NR. On the one hand, it wanted to ensure the station design would meet the concerns and aspirations of the Council for the future. On the other hand, NR was not in a position to make a huge capital investment in future proofing provisions if they were not underpinned by a solid business case. The cost of building the provisions described above amounted to be around £1M. It represented less than 1% of the £150M project budget of the station building. In the midst of a financial crisis, however, the business case for making these provisions seemed increasingly weak. There was also an issue about which party should incur the cost of designing in the provisions to make it easier to expand the Reading station in the future.

### 5.2.3 Salford Crescent redevelopment project

The Salford Crescent was an interchange and pedestrian railway station constructed in 1983 that since the early 2000s could no longer cope with the increasing demand. Located at a key railway junction between services based at Manchester's Piccadilly and Victoria stations, Salford Crescent offered an easy cross platform interchange for passengers on trains to and from Manchester Piccadilly (via Manchester Oxford Road) to interchange with Manchester Victoria Station. It also offered an important commuting link for students due to its proximity to the campus of The University of Salford, which had been expanding for more than two decades. In 2011, the University reached approximately 20,000 registered students and nearly 2,500 staff members, and was marshalling an ambitious capital programme to improve and expand its campus. Due to the increase in student numbers, the 1983 railway station building could no longer cope adequately with the new levels of usage at peak times. Overcrowding was exceptionally high at some periods of the day (Figure 5.3) to the extent in some occasions the presence of police was necessary to control the access of passengers.

**Figure 5.3: Overcrowding at the station during a rainy day (source: Manchester News)**

The poor arrangement of the furniture on the platform worsened the problem of overcrowding as it limited the space available for circulation. The Salford Crescent Station consisted of two platforms forming an island with a total width of 7m. This barely met the minimum standard width requirement for the construction of new platforms that was 6 metres clear of all obstructions. The station's canopy only covered a small portion of the platform island creating a relatively tiny area where the passengers all wanted to congregate during days with poor weather conditions (Figure 5.3). The platform was accessed through a stepped ramp that was linked to a right-of-way bridge over the railway (Figure 5.4). At the 'pinch-points' of the station (stepped ramp, ticket office, and waiting room), the space available for circulation was reduced to only 2 metres. This was a key constraint to the movement of passengers and also created a serious safety hazard.


**Figure 5.4: Narrow platform and ramp linking the platform to the right-of-way bridge (picture taken by G. Biesek Mar/2011 at Salford Crescent Station)**

The station also had problems in accommodating long trains. The platforms' length could only accommodate 5-car trains (assuming a standard car length of 23.76 metres), a constraint that put a few train operators off running their fleet on those tracks. First Trans Pennine Express (FTPE), for instance, was interested in operating in that railway line with 6-car trains of their Class 185 rolling stock. If it were to run such an operation its train would need a platform with a total length of 147.5 metres (assuming 5m for inaccurate stopping), which was above the existent 130-metres-long platform. The limited length of the platform was also an impediment to operating 8-car trains on the railway line, which was a future aspiration for FTPE. Another problem with Salford Crescent was its lack of compliance with the Disability Discrimination Act (DDA), which had introduced stringent standards in 1995. The access to the station for wheelchair users was inadequate, and 'train ramps' for interchange between trains were unusable due to the platform clearance issues. Since the station was built before the Act publication, it could legally remain non-DDA compliant. The minimum acceptable standards specified in the Act would need to be addressed, however, in any project to redevelop the station.

Clearly, Salford Crescent Station needed to be urgently redeveloped to bring the services it offered to acceptable standards. This would satisfy the long-term view of the Government expressed through the white paper ‘Delivering a Sustainable Railway’ published by the DfT in 2007. This document pointed out plans to develop a national rail network that could contribute to the broader economic and environmental goals of the country. Due to the capacity constraints, Salford Crescent was included in the National Stations Improvement Programme (NSIP). NSIP was a joint industry initiative funded primarily by the DfT to improve 150 medium-sized stations in England and Wales in order to help the rail industry meet targets in terms of performance, capacity, reliability, and safety. This programme aimed at funding directly projects to redevelop stations in urgent need, focusing on high footfall, low passenger satisfaction stations. In early conversations, NR expected that it could also entice the Greater Manchester Passenger Transport Executive (GMPTE) to contribute to the project funding. GMPTE, however, backed away after it was restructured in 2011 to become the Transport for Greater Manchester (TfGM), and only NSIP funding remained available.

From a timescale perspective, NR started front-end strategizing and planning the project in December 2009, with a view to undertake the construction works from November 2012 to July 2014. NR was leading the process, but other key stakeholders were involved in the early planning stages. It included the private train operator Northern Rail which also operated the station, the University of Salford, the City of Salford, the Urban Regeneration Company for Salford, and the GMPTE. NR’s planned to finish the project by the end of December 2014. To be successful, the project needed to: 1) meet the DfT High-Level Output Specification (HLOS) metrics; 2) contribute to minimise overcrowding on the railway network going through Salford Crescent; and 3) meet the Council's aspiration for the provision of direct Calder Valley[23] services to and from Salford Crescent.

To cope with foreseeable needs, the key project stakeholders discussed two key provisions that could be included in the scheme in order to facilitate its eventual adaptation in the future. First, the project team considered how to future-proof the scheme, in order to reduce the costs to potentially adapt the station for accommodating longer (and more profitable) trains at Salford Crescent in the future. Building a longer platform immediately was unviable as it would require not only £2.8M for the platform itself, but also an additional £20M for adjacent works, such as the need to rebuild all adjacent railway tracks and to modify adjacent signalling. Conversely, building the station without considering the possibility of adding a platform could prohibit its construction in the future due to great adaptation costs. An alternative was to build provisions at the approximate cost of £1M that would safeguard this scenario. This would allow the project team to cover the costs required to: (a) obtain ownership of the land adjacent to the railway to guarantee that the land remains free of potential new developments; (b) clear adjacent constraints imposed by footbridges or by roads over bridges, to avoid the need of demolishing them in order to extend the platform; (C) locate the signalling equipment in a way that makes its relocation easier in the future.

Second, the project team discussed the possibility of having a station building that would fit with the landmark building category. This idea was not consensual, and some stakeholders were unsure of the need to invest in an aesthetically pleasant building at Salford Crescent Station. Surely, such investment would add to the capital costs and was unclear which sources of funding could complement the NISP grant. This idea was attractive however to other stakeholders who felt a modern station could act as a catalyst to the broader programme to regenerate the Salford Crescent area. Three possibilities were under discussion for the station building. The first alternative was to build a pre-fabricated building at the cost of

[23] The Calder Valley line is a secondary route between Manchester and Leeds, serving the intermediate towns of Rochdale, Todmorden, Hebden Bridge, Halifax and Bradford as well as several other smaller stations. See appendix E for route map.

£849,375. This alternative would potentially require £1,524,358 in the future, if stakeholders decided to incorporate a landmark building. A second alternative was to build a pre-fabricated building with special foundations at a total cost of £1,029,375. This would allow the future replacement of the pre-fabricated building for a bespoke landmark building at the cost of £1,274,358. Finally, a third alternative was to build immediately a bespoke landmark building at the cost of £1,786,283. The three alternative costs are summarized in Table 5.3.

**Table 5.3: Costs for building station building**

| Alternative for the station building | Cost to build provisions for future adaptation | Total Upfront Cost | Cost of Adaptation (i.e., to make it a landmark building) |
|---|---|---|---|
| Build a simple pre-fabricated building | - | £849,375 | £1,524,358 |
| Build a simple pre-fabricated building with built-in option to allow its replacement by a landmark building in the future | £180,000 | £1,029,375 (£849,375 + £180,000) | £1,274,358 |
| Build immediately a bespoke landmark building | - | £1,786,283 | - |

Across the three projects, I systematically observed opportunities for future-proofing. Whilst I observed great variance in the number of key project stakeholders at front-end strategizing as well as in the size of the project, the need to select the stakeholder in a better position to fund the future-proofing provisions surfaced systematically. The next section analyses how this future-proofing problem was resolved across the sample.

## 5.3 Design for Evolvability in NR capital projects

In new capital projects involving multiple funders, early design decision-making in front-end strategizing invariably becomes intertwined with negotiations to forge multilateral agreements determining which party funds what (Gil & Tether, 2011). Presumably, these negotiations become even more critical as western societies enter an age of austerity. This is certainly true for NR capital projects wherein typical stakeholders and potential funders included NR, the DfT, local authorities, private train operating companies, and regeneration agencies. The comparative analysis of the three capital projects corroborates theory (Gil, 2007) by suggesting that some level of intuitive options logic systematically supports early design decisions around whether or not to future-proof. The analysis also reveals that the multilateral conversations to agree the options to design are invariably challenging because of the intertwinement of the early decisions to design selected options with the need to agree which stakeholder incurs the capital costs associated with those options. This is important as the literature on real options – most of which is grounded on strategic decisions to invest in capital assets – often assumes that the cost of buying the option is negligible relatively to the value the option can deliver and relatively small compared to the budgets of the organisations considering whether to pay a premium for the assets with built-in options (Neufville & Scholtes, 2011). This research explores a different setting. The findings suggest that the decision to allocate some capital to design an option is rarely trivial at project front-end strategizing. Furthermore, these findings suggest that the risks that conversations around design optionality that may unravel in front-end strategizing are particularly high whenever: (1) multiple parties are expected to fund the project in its totality; (2) the organizations insisting in designing particular functional or operational requirements do not have the wherewithal to contribute to fund them; and (3) the stakeholders sitting at the negotiation table exhibit sharply different planning horizons, technical capabilities, and conflicting priorities. This problem is compounded since these decisions need to be taken at the early projects stages when limited information is known about the project and uncertainty is high about the future. Table 5.4 summarizes the evidence uncovered on how this challenge played out across the three capital projects, and illustrates the discussion that follows.

**Table 5.4: Description of the Project Front-end Strategizing in the Sample**

| Project | Warrington | Reading | Salford |
|---|---|---|---|
| Scope | Build a new rail bypass (chord) to connect two freight lines | Build new platforms and concourses; improve layout of the infrastructure | Improve existing platforms and station building; improve layout of the station furniture |
| Aim | Project releases land and access to waterfront, and can act as catalyst for local regeneration | Increase the overall capacity of a critical railway station | Reduce overcrowding on the platforms, and increase capacity of the railway station |
| Anticipated Final Cost (AFC) | ~£15M | ~£150M (station); whole project costs over £800M | ~£12M |
| Front-end strategizing | ~2 years (Oct 2008 - Dec 2010) | ~2 years (Feb 2006 - Jan 2008) | ~1.5 years (May 2009 - Sep 2010) |
| Planned duration for design and implementation | 6 years (2008-2014) | 9 years (2006-2015) | 5 years (2009-2014) |
| Number of key stakeholders | Moderate<br>*NR, Council, Freight Operating Companies, regeneration agency* | Moderate<br>*DfT, Council, NR, Property Developers, Train Operating Companies* | High<br>*University, NR, Train Operating Companies Council, regeneration agency, other public agencies* |
| Heterogeneity across stakeholder' interests | High<br>*"I cannot understand why NR is asking that we [Council] have to pay for allowing future electrification"*<br>[Councillor] | High<br>*"It took a lot of effort [to reject Council's ideas] and made us look pretty poor"*<br>[NR programme manager] | High<br>*"The rail industry is - quite clearly - incredibly complicated and bureaucratic"*<br>[Regeneration agency representative] |
| Potential sources of funding | Multiple<br>Council, regeneration agency, NR | Multiple<br>DfT; NR; Council; property developers | Multiple<br>DfT; NR; Council; University; regeneration agency |
| Sense of urgency | Debatable<br>Low for NR, but high for Council to seize opportunity to get third-party funding | High<br>Need to resolve capacity bottleneck, for which NR is paying penalty fees | High<br>Closure of station imminent unless redevelopment goes ahead |

### 5.3.1 Intertwinement between early design decision-making and multilateral 'money talks'

Invariably, the analysis of the cases shows the challenges faced by multi-stakeholder teams in seeking to reach a satisfactory agreement at the early stages of the project. The case of Warrington, a project not very complex technically, is telling. This £15M project to provide a new railway chord connecting two freight lines lacked a compelling business case for NR. The company admitted the new chord would improve working conditions at the depot and eliminate inefficient run-round and turn-back manoeuvres, which would allow the freight operators using the line to save journey time. NR priorities, however, were clearly geared towards the modernisation of the passenger lines that connected directly to the west coast main route, as opposed to modernise a line that was used by freight operators. Accordingly, the project was framed as a third-party scheme in the NR's capital programme for the Control Period 4. This meant the project would only go ahead if the Council or other third parties were willing to fund the scheme in its totality. For the Warrington Council, however, the project was vital to regenerate its waterfront. The Council had been lobbying for this project for almost 20 years. The existing layout of the railway lines and associated sidings cut off pedestrian access from the city centre to the waterfront, pre-empting any chances of enticing developers to invest in that part of the city. If the scheme went ahead, the existing NR assets would be made redundant by the new chord. They could then be demolished, and the land could be released for development over the next 30 years according to the town's masterplan. The Council, however, had very limited understanding of the fundamental issues affecting the design and delivery of railway projects. Despite assigning a strategic consultation manager to lead the project, the Council remained strongly dependent on NR's technical expertise to resolve concept design. NR's project manager clearly understood that:

> "It's our job to present the information unbiased. We've to clearly say: 'look, these are your options'. And we try to present the information to enable them [Council] to make their own decisions. This is important because, although they rely quite heavily on our advice, ultimately the accountability is with them, the funder."

The Council's lack of familiarity with the railway industry amplified the funding problem. The Council was frustrated that NR insisted in framing its role strictly as a supplier to a third-party scheme. It also felt unfair that NR was demanding that the Council funded specific investments in design provisions to make more economical any eventual further modernization of the rail infrastructure. Whilst the Council did not totally disagree the scheme needed to be future-proofed, it questioned the need for all the provisions, and was surprised that NR as the owner of the infrastructure was unwilling to contribute to the capital costs:

> "NR seem to be treating it as a third-party project; there's nothing there [in the NR route utilisation strategy] about potential benefits in terms of track maintenance, release of land values, and nothing for train operators in terms of saving running times" [Councillor]

Likewise, early design decision-making for the Reading Station was highly intertwined with multilateral negotiations regarding funding issues at front-end strategizing. The key stakeholders unanimously considered that the project was critical to resolve the severe capacity constraints that were forcing NR to pay heavy fines to the train operators. They also agreed that the redevelopment presented an opportunity to build extra capacity to cope with further increases in passenger demand over time. From a Council perspective, however, the scheme also created a unique opportunity to design a station building that could catalyse the development of the area around the station, an area that had been neglected for many decades. This posed a conundrum for the project team. NR had received funding for the station redevelopment project from DfT to strictly meet the statutory performance targets in terms of reliability, capacity and safety. NR was unwilling to top up the government grant to enhance further the design of station in light of foreseeable developments in the surrounding area. The Council found unacceptable that the design would not be future-proofed to cope with future developments, but lacked the financial resources to design the necessary provisions.

Interestingly, the complexity of the intertwinement between multilateral 'money talks' and early design decision-making could equally apply to smaller projects. A good example is the redevelopment of the critically overcrowded Salford Crescent Station. This was an urgent project undisputedly since the lack of space for circulation at the platform posed serious risks to passenger safety. Project front-end strategizing was nonetheless complicated. The design concept needed to reconcile criteria in a DfT-sponsored programme providing £150 million of funding to support short-term improvements with NR's own long-term vision (encapsulated in its Route Utilisation Strategy for the North West), and other stakeholders' short- and long- term visions.

The case illustrates well the complexities of the multi-stakeholder negotiations at early design decision-making. Northern Rail, the short-term franchised station operator that also operate trains at this station, was keen to endorse a design that would enable both its company and the other private train operator, FTPE, to operate with 6-car trains (the station only accommodated the less profitable 5-car trains). However, Northern Rail had a franchise only until 2014 for operating the station, and renewing the contract was always dependent on service quality inspections and the quality of bid proposals. With no guarantees of obtaining future franchise contracts, Northern Rail could potentially have little to gain in endorsing a scheme that planned not only to modernise the current island platform and extend it but also to add a third platform. Such a scheme would significantly increase the amount of disruption to operations during the construction period, which were expected to take place during its franchise. Northern Rail understood that a third platform would enable them to meet an aspiration to connect Salford Crescent to Calder Valley services which could eventually be good for the business in the long term although there was uncertainty about whether the demand would materialise. In the short term, however, its operating costs were likely to increase if a more comprehensive redevelopment went ahead. As a profit-seeker, Northern Rail would only be prepared to endorse the scheme if NR and other parties could provide assurances the firm's financial returns would not be hurt by the redevelopment.

In contrast, the University located on both sides of the station felt entitled to ask that a third platform be designed in the redevelopment scheme. The increase in capacity enabled by a third platform was the right fit to the University's £100M capital expansion programme that was rolling over the next 20 years. The Council and public agencies in turn clearly understood the project was important to advance their agendas for local regeneration and sustainable commuting. Central Salford Urban Regeneration Company (URC) viewed itself almost as a client since they were driving a £4bn capital programme to regenerate Salford in partnership with the Salford City Council. GMPTE was also interested in ensuring the design of the scheme was in line with its own plans to build a new bus/rail interchange. However, both parties balked at any suggestion of using their own limited funds to enhance the design of the railway infrastructure and of the station building. Central Salford URC's funding capability in particular was severely reduced after the new coalition government elected in 2010 started to cut the amount of central government funding flowing into regional development agencies. In 2011, Central Salford URC formally ceased operation after it lost its two major funders: North West Regional Development Agency and the Homes and Communities Agency. GMPTE's situation was not dissimilar. The organisation was also going through significant changes to its structure to adapt to an age of austerity, and in 2011 it folded into Transport for Greater Manchester (TfGM).

The struggle to secure funding was not uncommon during the front-end strategizing of railway projects, and political changes were but one factor that made the whole process so protracted. The delays in front-end strategizing were in fact inherent to the process given the invariably large number of stakeholders that needed to buy into the vision. Not oblivious to the challenge of satisfying multiple stakeholders' needs and of agreeing on a future-proofed concept design which was successful in acquiring a collective commitment to fund, the NR project manager confided: "we don't want to come up with a design for putting a really basic ticket office and if you want to improve it in the future, you'll realise you cannot do it because of the way we did things now". Invariably, the fieldwork reveals that designing options in multi-funded capital projects is a major front-end strategizing challenge. The difficulties stem in part because the decisions are intertwined with short-term affordability issues. It is also clear that different stakeholders will not necessarily agree on what actually needs to be designed and who should pay for it. The next section analyses the extent to which the multi-stakeholder teams use options logic informally to tackle the complexity of this problem.

### 5.3.2 Negotiating Design for Evolvability: informal use of options logic

Notwithstanding challenging stakeholder issues, the analysis of the cases reveals that multi-stakeholder project teams systematically resort to informal options logic to frame concept design problems at front-end strategizing. The source of ideas for designing options varies. Engineers may propose building options to reduce the costs of adapting the asset to foreseeable technical modernization of the rail infrastructure, whereas public agencies may propose building options that are aligned with their agendas for socio-economic development and urban regeneration. The findings also suggest that the decision-makers repeatedly need to collectively think through multiple potential options which compete with one another for a limited if not fixed pot of funding – a problem that is very hard to model analytically (Driouchi et al., 2009). Interestingly, the options themselves are seldom technically complex to build in concept design. Rather, they may require mundane investments in design provisions to facilitate future growth, stage delivery, or build operational flexibility. Importantly, the advocator for designing in an option cannot be assumed to be in a position to fund the upfront costs of the design provisions associated with the option. Table 5.5 summarizes the evidence on main issues surrounding the options that were considered across the three projects.

**Table 5.5: Summary of evidence on the intertwinement between informal options logic and money talks at front-end strategizing**

| Project | Warrington | Reading | Salford |
|---|---|---|---|
| Sample of options to potentially leave open | (1) Electrify railway line; (2) Increase rail gauge from W10 to W12 | Connect station building to private development | (1) Add third platform; (2) Develop landmark building |
| Types of option | Switch operations (1,2) | Stage delivery | Grow capacity (1) stage delivery (2) |
| Perceived option value | Reduce costs of potential modernization of the railway line in the future (1,2) | Reduce costs of a potential development of the station building | Reduce costs of potential need to increase the capacity of the station in the future (1); future modernisation (2) |
| Advocator | NR technical division (1,2) | Council | Multiple stakeholders (1,2) |
| Additional cost to design in options | ~£0.5M (~2.5% of total budget) | ~£1M (less than 1% of total budget) | ~£1M (~10% of total budget) just to leave option to add a platform open and over £20M if a new platform were to be built now (1); £180,000 (2) |
| Assessment of options value | Informal:<br>If option is not designed in now, the need to demolish and build again will make electrification unaffordable | Rudimentary cost-benefit analysis<br>If option is not designed in, it will be significantly more difficult to entice private developer to invest | Informal (1),<br>If option is not designed in, the idea of adding a third platform in the future will become even more unlikely to ever happen;<br>Informal, inexistent (2)<br>Nobody formally analysed/communicated the consequences of building (or not) the option |
| Funding issues | NR expects the Council to pay for the options, but Council says it cannot afford | The Council wants NR to build the option and pay for it, but NR is struggling to cover the enhancement within the government grant | Public agencies deem that designing in the option is the right thing to do, but NR notes the government grant does not cover railway line enhancements (1); relatively low cost of option led to inclusion of costs in the budget without appropriate analysis |

Overall, the findings suggest that efforts to informally implement options logic at concept design are rarely straightforward. Rather, the design decision-making process gets systematically delayed due to its intertwinement with challenging multilateral negotiations of trade-offs under conditions of uncertainty, conflicting priorities, asymmetries in technical knowledge and capabilities, and scarcity of capital resources. As one respondent put it “it’s amongst the easiest things to identify what we might do to future-proof, the hardest is to say who’s going to pay for that?” Because the decision-making process happens in rather informal terms, the findings also suggest that the quality of the multilateral conversations and outcomes vary widely as a function of people’s personalities, capabilities, and personal beliefs. As one NR engineer put it: “I future-proof. That’s me doing what I believe is right. I believe in railways and the service they provide. But that doesn’t play into the corporate vision; perhaps I’m wasting company money”.

The Warrington case illustrates well the challenging intertwinement between informal options logic and ‘money talks’ at early design decision-making. Whilst NR framed it as a third-party project, its design team proposed a number of provisions to reduce the costs of a potential modernization of the rail infrastructure. Specifically, it proposed to design a new viaduct over the new chord with enough volumetric clearance so it would not need to be demolished if the rail line is changed to a larger gauge (a prerequisite to increase capacity) and/or electrified in the future (a change needed to lower $CO_2$ emissions); as the senior route planner put it: “the scheme would not survive any network change consultation if otherwise”. Intriguingly, It remains unclear the extent to which the team within the Council scrutinised the original budget presented by NR and noticed NR’s position to pass to the costs of future-proofing the scheme to the Council. The scheme has remained in GRIP 2 stage since it was first initiated in 2009, and it remains unclear whether the Council will be able to fund the scheme on the terms NR is proposing.

The Council has been struggling to find the means to fund the project after the new elected government in 2010 scrapped the regional development agency – the entity that would potentially have the wherewithal to fund the physical works. Technically, the project remains listed in the Council’s capital programme as a scheme to happen in 2013/14. Intriguingly, the budget has evolved to £18.6M. This suggests a massive commitment considering that the Council’s overall capital budget for the three years is £165m, of which £47m to be invested in 2014/15. It also continues to show on NR’s list of capital programmes for the route as a third-party scheme that will happen in 2013 or already in 2014, the control period 5. Interestingly, in 2012, a new elected Councillor for the project's ward (who had worked on railways for 10 years) started to challenge the budget. Specifically, the Councillor is championing a debate about who should pay for what given the potential benefits that the scheme can bring to NR and operators. On the issue of future-proofing, the Councillor notes for example:

> "If NR expects everybody else to fund the project, do they think there's no benefit to themselves? It also seems they're costing for double track, and it's just a chord – why do we need double track if the traffic is not that heavy? And is it worth spending money at all making provisions for electrification? I need to ask these questions. I'm also planning to take a go at the two freight companies and ask them what their thoughts are."

The redevelopment of the Reading Station brings another example of the complicated intertwinement between using options logic and 'money talks'. It also shows how ad hoc asymmetries of technical knowledge and power to influence decisions can ultimately determine whether options are framed as 'nice to have' as opposed to 'have to have'. After NR was awarded funding for the project by the DfT, the Council became interested in seeing NR committing to connect the station to the Station Hill – a potential £400M private development in a 5-acre area adjacent to the station. To this purpose, the Council asked NR to incorporate provisions that would allow economically connecting the station to the area and further expanding the concourse in the future. No private developer had yet committed, however, to make the required investment and the financial crisis made it difficult (and still makes) to predict how things will pan out. Together, the built-in provisions would add over £1M in capital costs which NR had not factored in when it bid for DfT money. The case findings were inconclusive as to whether NR consulted the Council properly when it put together the bid to the Government. However, they show that an agreement to design provisions in the scheme in order to leave the option to develop the station further open was protracted. Whilst the Council insisted the provisions needed to be built in the design, it had no means to fund the costs. NR, in turn, was reluctant to incorporate these provisions unless a third-party was willing to fund them. After much haggling between the two main parties, NR agreed to do it as it simultaneously managed to find savings elsewhere in the project, maintaining the scheme within the original overall budget. Importantly, the fieldwork suggests that the outcome hinged in part on the Councillor's personality who sat in a position that NR people perceived could influence the outcome of the planning application. As the NR programme manager put it:

> "This Council person, a very strong character, was probably the reason why these ideas went forward. I mean, NR's view is to do what we've been asked to; as an organization we don't really care about the streets of Reading. And DfT, well, that's not their game."

In contrast, the case of Salford Crescent reveals an environment where front-end strategizing was equally protracted albeit negligible asymmetries in knowledge or perceived power across stakeholders. A fundamental issue was central to the intertwinement of informal options logic and 'money talks': the cost to be incurred in the present to add provisions so it would be less expensive to build a third platform in the future. There was high uncertainty particularly as to whether a costly third platform (around £30m) will ever be added to the station. With the exception of the station operator which operated under a short-term franchise contract, the idea of building this option was well aligned with the strategic visions of most stakeholders. NR was interested in growing capacity, even if a NR respondent asked rhetorically 'how many of us really read the route utilisation strategy? do we understand it?' The option was also aligned with one of the long-term plans of the station operator to allow more services stopping at Salford Crescent, the University plan to expand its campus, and the public agencies' interests in furthering socio-economic development. For example, representatives of Central Salford URC asserted:

> "In ten years time, this station will be completely different because the University is going to grow, and they're changing their estate. The roads that run pass are also going to be developed. We're spending something in the region of £40M at the moment!"

At the same time, high uncertainty existed around the materialisation of these visions in an age of austerity. As a NR representative put it: "the trick is working out a realistic scenario in ten years time. What wasn't realistic in the past might be realistic now. And sometimes it comes down to crystal gazing your assumptions". The University, for example, could not pin down reliable projections for growth in student numbers since undergraduate fees were about to significantly increase, whereas the other public agencies were struggling financially in the aftermath of the financial crisis. As a result, these interested parties shied away from committing any funds to build the provisions in the design. In turn, the NSIP government scheme, the mechanism to fund the project, excluded investments in new platforms or in modernizing the railway line. Delays in reaching an agreement were exasperating to the extent the NR commercial sponsor warned in one meeting that 'if you don't come along with the funding, sooner or later, we'll have to put something in there'. Eventually, the decision-makers collectively agreed necessary trade-offs that enabled to build limited design provisions for a third platform and landmark building. Both provisions would be funded by the government, but only the funding for the landmark building would come from NSIP scheme. Since NISP policy rules out extensions of funding to track or signalling improvements, the funding needed to add a third platform would be included in NR's government allowance, CP4.

## 5.4 Final considerations

All in all, the findings reveal that multi-stakeholder teams systematically resort to a combination of informal options logic and 'money talks' to resolve concept design at front-end strategizing. This is true both for NR engineering-driven options as well as for development options driven by third parties. The conversations underpinning the decision outcomes invariably unfold under conditions of high uncertainty about the future states of the world, conflicting priorities, and asymmetry in technical capabilities and power to influence decision-making. Hypothetically, the lack of any formal framing for problem-solving contributes to delay the decision-making process and can, arguably, lead to issues of fairness and ethics in the management of the stakeholders (Phillips, 2003). For example, one NR respondent thought the informal decision-making process for building engineering-driven options seemed to reward those ‘who get it wrong, who fail to plan for the future but save on capital costs’. Another respondent argued that a line needed to be drawn somewhere to prevent wasteful investments driven by “wonderful utopias of modernizing unprofitable lines with hundreds of low bridges and tunnels”. The challenge of designing engineering-driven options could get amplified in third-party projects if a well-informed client challenged the NR presumption that the client should foot the bill. Equally, the outcomes of conversations around investments in development options were hard to predict as they hinged on unstructured multilateral talks not necessarily attended by the relevant parties. Tensions invariably surfaced whenever the NR team argued that NR should not bear the costs to incorporate these options in the design, whilst public agencies lacked the wherewithal to fund them and private developers demurred to commit. Overall, the delays to resolve the complicated intertwinement between options logic and ‘money talks’ points to an opportunity to formalise a design for evolvability framing. As a senior NR official noted:

> “We’ve to have a basic understanding of which direction we want to go. I think this is what we’re talking about with evolvability. It’s almost like when we brought in value management – we always did it unscientifically and then became more formalised. I think this [design for evolvability] is about a structure behind asking the question: is there something we could do to ‘future-proof’ and start off doing all this?”

The next chapter proposes a design for evolvability framing that emanated from the cross-fertilization of the literature in real options and project management with the empirical studies. The subsequent chapter then introduces a two-group controlled experiment grounded on the Salford Crescent case that was used to test the proposition that a formal design for evolvability framing adds value to front-end strategizing capital projects. Specifically, the experiment was adopted to investigate a core question: can formalizing design for evolvability help multi-stakeholder teams strike the right balance between short-term affordability and long-term adaptability at project front-end strategizing?

# 6 A Proof-of-Principle of a Method to Design for Evolvability

## 6.1 Introduction

The aim of the development of a proof-of-principle of a *Method to Design for Evolvability* is to enable the investigation of the usability of the *Design for Evolvability framing* and its underlying principles. The design for evolvability framing aims to support early design decision-making at the front-end strategizing of capital projects. More specifically, it formalises the use of options logic at the early design stages of a capital project by offering a structured decision-making process to support multi-stakeholder teams. Hence, the proof-of-principle presented in this chapter works as a research instrument through which the usability of the proposed design for evolvability conceptual framing will be validated.

Three main propositions derived from playing extant literature against the empirical studies underpin the development of the design for evolvability proof-of-principle. First, I argue that a formal design for evolvability framing is necessary to enable multi-stakeholder project teams to make better informed decisions on which provisions should be incorporated in the design of a new asset to cope with foreseeable uncertainties. Second, I argue that a structured qualitative protocol based on options logic is suitable to help project teams to make relatively mundane design decisions, which would not lend themselves to be supported by sophisticated mathematical models based on options pricing theory. Finally, I argue that a qualitative design for evolvability protocol can be critical to encourage the multi-stakeholder teams to discuss and agree at the early design stage of the project development how to allocate among the stakeholders' budgets the upfront costs that need to be incurred to implement the design provisions. Equally important, this protocol also promotes the discussion on who should pay for the costs that need to be incurred to exercise the built-in options at a later date if uncertainties resolve favourably.

To implement a design for evolvability protocol in the early design stage of a project, I propose to create an institutional role as a coordination mechanism (Bechky, 2012) – *Champion of Design for Evolvability.* The Champion should be trained on the principles and science underpinning the method to design for evolvability, which are largely derived from the field of real options. To be effective, the champion also needs to be empowered by the project promoter with authority to advise the multi-stakeholder team to adopt the design for evolvability protocol in the design decision-making process. This protocol consists of three iterative stages: 1. *Analysing Options*, 2. *Designing Alternatives*, and 3. *Project Strategizing*. Each stage, in turn, encompasses a sequence of steps aimed at producing a deliverable that feeds into the next stage (Figure 6.1). The following sections will explain in detail each of these steps and the role of the champion of design for evolvability.

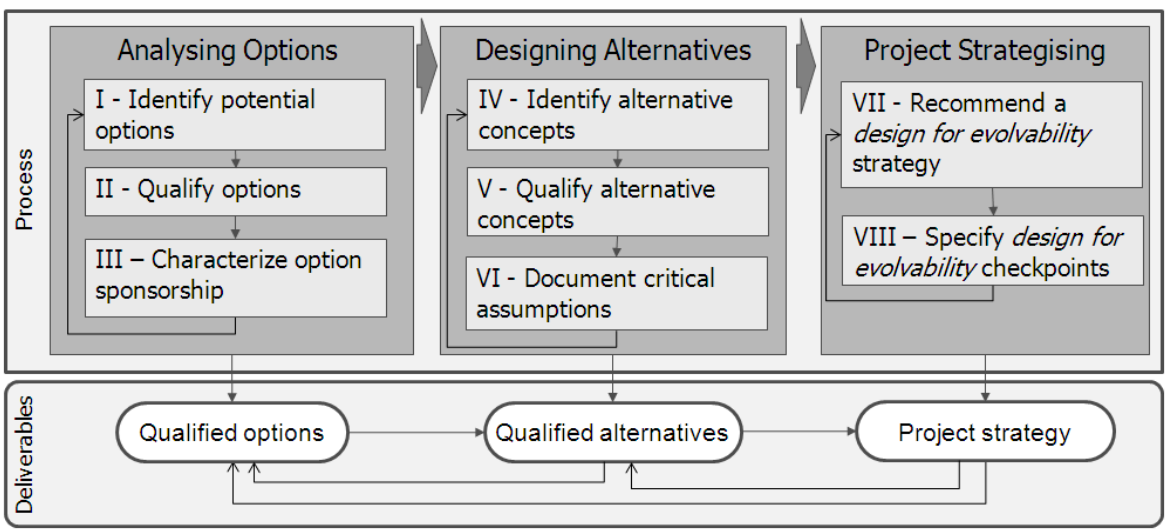



**Figure 6.1: Schematic representation of the method to design for evolvability.**

## 6.2 Part 1 – Analysing Options

In the first stage, the project team has to identify potential options to build in the design definition. To this purpose, the different stakeholders in the team need to look at how the strategic visions of their respective parent organisations may translate into operating scenarios for the new asset, which in turn point to potential options that can be designed in the concept. The members of the team have to collectively qualify these options resorting to the conceptual variables and relationships defined in formal options logic. This may include, for example, the need to identify plausible ranges for the exercise and expiration dates of each option, the likelihood that an option will be exercised in the future, and the value that can be created if uncertainties resolve favourably. The team also has to characterize the option sponsorship, a crucial step to start a conversation on which stakeholder is in a better position to fund, first, the upfront costs that need to be incurred to design in each option, and second, the costs to exercise these options at a later date. The final output of this stage is a document describing in detail and qualifying the potential options to design. This deliverable is called *Qualified Options*.

### 6.2.1 Identify Potential Options

The first step in the Analysing Options stage consists of identifying potential options. During the early stages of the project lifecycle the design team has to identify and understand potential future scenarios. The champion of design for evolvability will first ask the project stakeholders to check whether their parent organisations have developed a strategic vision. Second, the Champion will ask the stakeholders to check the extent to which any eventual strategic plans translate into a range of possible operating scenarios and particular design requirements for the new asset in the future. After each stakeholder undertakes this exercise and identifies plausible future scenarios, they should use this intelligence to identify potential options that can be built into the design of the new asset in light of foreseeable uncertainties in functional and operational requirements.

To facilitate the identification of potential options, the stakeholders should also investigate whether their parent organisations already have lists of built-in options that may have been developed for comparable projects in the past. Whilst capital projects tend to be one-off, many similarities tend to be found at the development process level from project to project. In railway projects, for instance, a number of optionality issues tend to systematically emerge whenever a new railway infrastructure is designed. For example, designers invariably need to discuss whether the railway lines will be electrified in the future, and accordingly whether the height of new bridges over the railway should leave sufficient leeway to account for that scenario. It is therefore plausible to assume that stakeholder organisations that own portfolios of capital projects with similar characteristics – such as NR or an airport owner like BAA – should have built over time a knowledge repository that captures design uncertainties that recur systematically, and design provisions that need to be accounted for in new projects. This information can be useful to inform and speed up a conversation on design for evolvability. It also ensures that standardized strategic rules in regards to design for evolvability are systematically applied to different projects. For instance, rules that establish a minimal height for railway bridges over lines earmarked for electrification in the future should be documented into the central repository.

### 6.2.2 Qualify Options

Once the potential options have been identified project teams need to qualify these options, i.e., characterize the value that they add to the new asset vis-a-vis the costs that need to be incurred to design in the option and exercise it in the future. To qualify the options, the champion of design for evolvability will ask project stakeholders to characterise these options against a number of parameters derived from options logic. First, the team has to assess the value to be created if uncertainty resolves favourably and the option is exercised. To assess this value, the teams should look to a number of parameters namely: the impact on the business case, i.e. impact on benefit to cost ratio as described in an extended net present value analysis; as well as the appetite of different stakeholders to fund the additional capital costs that need to be incurred to design in the option upfront. The team has to assess the potential amount of rework costs that would need to be incurred if uncertainties resolve favourably but the option is not designed in. Whilst the assessment of the value of each option can technically be done through options pricing models, the empirical findings of this thesis suggest it is unlikely that the effort to quantify the variables and relationships would pay off for mundane design decisions. More appropriate, it is to suggest that the stakeholder teams engage in a qualitative discussion of the rationale for designing, or not, particular options and the cost implications in the present and in the future.

The multi-stakeholder team also has to discuss when they expect to make use of each provision built in the design definition. This provides the sponsors of the design provisions, i.e., the stakeholders that will incur the capital cost for buying the built-in option, with a sense of when they may be likely to obtain a return on the investment. Stakeholders have to therefore indicate the expected timescale for exercising the option and whether the option eventually expires at some point in the future. In options logic, the expiration date is the date after which an option can no longer be exercised, whereas the exercise date defines the expected timescale for undertaking the right to exercise the option. Some options might never expire, a.k.a. perpetual options (Howell et al., 2001).

Finally, the champion of design for evolvability needs to guide the team to estimate the likelihood that each option will be exercised. Decision-makers operating in environments where capital resources are scarce tend to find attractive investments in options that are likely to be exercised in the near future. Conversely, these decision-makers might be reluctant to invest in options with high uncertainty as to when they may be exercised. They can be especially reluctant to invest in options that may take decades before they will be exercised if they identify more urgent priorities for allocating the scarce capital available in a fixed budget (Gil, 2007). It is critical that the champion of design for evolvability shares his/her expertise at this stage. Whilst decision-makers have to manage priorities, the champion should elucidate that the option value actually increases with long expiration dates. Longer expiration dates allow more time for uncertainties to resolve favourably and thereby more time for decision-makers to exercise the option. Table 6.1 summarizes the main variables that need to be factored in when qualifying an option. The completion of this deliverable is obtained with a discussion on the sponsorship of the options – the topic of the next section.

**Table 6.1 – Stage 1 Deliverable: Qualified Options**

| **Option A** | **"insert title of potential option here"** |
|---|---|
| **Foreseeable uncertainty** | "spell out the motivation for designing in this option" |
| **Design requirements** | "describe the range of design requirements that might be needed" |
| **Estimated additional value** | "estimate the expected range for the value of the option" |
| **Expected timescales** | "spell out when this option may be expected to be exercised" |
| **Potential expiration date** | "indicate date when the option can no longer be exercised (if existent)" |
| **Likelihood of being exercised** | "spell out the likelihood of exercising the option in the above timescales" |

### 6.2.3 Characterize Option Sponsorship

To conclude the first stage, the project stakeholders will be asked to characterize the sponsorship for each option. The champion of design for evolvability is responsible for starting a conversation regarding which organizations are in a position to fund the whole (or at least part) of the capital costs to design each option. The analysis undertaken in the previous step provides the project stakeholders with the means to identify who the potential sponsors can be, as well as the extent they are in a position to commit to fund the option. By having a conversation around 'who pays?' embedded in the formal discussion to qualify the options, the team is able to better understand which organizations would most benefit from the additional value that each option would create. The early discussion on the option sponsorship hence is instrumental to help the team identify the most appropriate stakeholders to fund the options, and crucially, whether they have the wherewithal to do so.

## 6.3 Part 2 – Designing Alternatives

In the second stage the project team has to identify alternative designs that vary in the extent to which the options previously identified are built in the design definition. The extent the alternative concepts show built-in options or not inevitably affect the upfront and eventual adaptation costs of the asset in the future. Plausibly, the greater the upfront investments to build in the options, the less costly it will be to adapt the asset to changes in requirements. Assessing the costs of the alternative design solutions and comparing them with the estimated value that each alternative can add to the project helps to determine the appropriate level of flexibility that should be built in the design of a new asset. The team will undertake such assessments by characterising key features of the alternative concepts (with different levels of flexibility built-in) and of a baseline scenario (without built-in options). The champion of design for evolvability is tasked to educate the team regarding the implications of ruling in and out provisions to build options. The champion in particular should highlight that making a relatively small capital investment in the present – provided the investment is affordable and sensible – may prevent difficulties later on in the project, notably unaffordable adaptation costs that at the limit can make the asset obsolete. To conclude this stage, the team needs to check the sponsors' commitment to fund the built-in options, and document any critical assumptions. By the end of this stage, the team will be able to produce the second deliverable – *Qualified Alternatives* – which details the alternative design concepts and costs.

### 6.3.1 Identify Alternative Concepts

In the first step of the second stage, the champion of design for evolvability will ask the project teams to identify alternative design concepts. Concepts that may have surfaced in previous projects should be considered – there is no need to reinvent the wheel for every new project. Importantly, the purpose of this step is not merely to raise alternative design solutions to address immediate design requirements – an exercise which is often performed through the so-called 'optioneering appraisals' (Gil, 2009). Rather, the purpose is to also discuss alternative ways to build in options to cope with foreseeable changes in the future. Particular attention should be given to whether the design architectures can be modularised, as by definition modular designs have options built-in (Baldwin & Clark, 2000). Alternatively, if modularity is difficult to achieve options can be built in integral architectures through investments in design safeguards, e.g., over-sizing foundations, increasing floor-to-ceiling heights, making conservative equipment choices (Gil, 2007). Project teams will also be asked to consider a baseline scenario that rules out investments to build options.

### 6.3.2 Qualify Alternative Concepts

Once the design concepts have been identified, project teams will be asked to assess each alternative in terms of the upfront costs to build in the options and the expected cost of exercising the options in the future. Teams should also assess the cost of adaptation for the baseline scenario (without built-in options) assuming this scenario does not prohibit adaptation (Table 6.2). The champion of design for evolvability will be tasked with educating the project team on the implications of ruling in and out potential options, using examples for the sake of illustration. For instance, safeguarding the option to add more storeys to a building by over-sizing its foundations and columns increases the construction costs. However, it reduces the cost of disrupting operations and adding the storeys in the future, enhancing the building's adaptability to changes in requirements. Alternatively, the project team may choose to make a more moderate investment that nonetheless guarantees that adaptability will not be prohibited in the future. For example, a project promoter could opt to oversize the foundations which are very costly to retrofit, but could decide not to oversize the columns which are more accessible if they need to be retrofitted in the future. The latter option will be unarguably more affordable initially, but if uncertainties resolve favourably in the future, the adaptation of the building will be more costly and certainly a lot more disruptive to operations in the future. Therefore a clear trade-off is articulated ultimately requiring a judgment call by the decision-makers. For the baseline scenario (e.g., do not even over-size the foundations), the building adaptation in the future may eventually be prohibitively costly. This would then represent a risk of the building becoming prematurely obsolete if uncertainties result favourably. Mindful that estimating the cost of exercising options might be challenging, as projections need to be made into the future, the champion of design for evolvability should ask teams to estimate ranges of values, as opposed to produce single-point estimates. As the teams pin down information on the costs, they should double check whether the option sponsor(s) can indeed commit to fund upfront and exercise costs (in case the option is built-in) or eventual adaptation costs (in case the option is not built-in).

**Table 6.2 – Stage 2 Deliverable: Qualified Alternatives**

| **Option A** | **"insert title of potential option here"** | | |
|---|---|---|---|
| **Alternative concepts** | Baseline Scenario: No option built-in | Alternative 1: Option partially built-in | Alternative 2: Option fully built-in |
| **Brief description** | “insert description here” | “insert description here” | “insert description here” |
| **Additional upfront costs** | 0 | “insert upfront costs” | “insert upfront costs” |
| **Exercise / adaptation costs** | “insert adaptation costs” | “insert exercise / adaptation costs” | “insert exercise/adaptation costs” |

### 6.3.3 Document Critical Assumptions

To conclude this stage, the champion will ask project teams to document the critical assumptions made for qualifying the options and alternative concepts. This step enables the project team to revise these assumptions when more information becomes available in the future. The impact of the assumptions to the assessment of future adaptation costs will vary across the numerous assumptions that may have to be made. Hence, the champion has to ensure that project teams flag up the most critical assumptions. The precision of these assumptions can then be revised in the future.

### 6.4 Part 3 – Project Strategizing

In the final stage, the project team has to recommend a design for evolvability strategy as part of the front-end strategizing effort. This strategic recommendation needs to be produced as an additional element to conventional 'optioneering appraisal' exercises, rather than a substitute. The purpose is to ensure that multi-stakeholder teams use options logic to assess eventual investment decisions to build in provisions to cope with foreseeable changes in requirements. In addition, the champion wants to ensure the team specifies checkpoints throughout the project lifecycle when it will assess the validity of the assumptions underpinning the design decisions. The checkpoints need to be set up in a way that fits with the capital development process adopted by the leading party. The final output of this stage (and of the whole front-end strategizing process) is a project strategy for a capital project. It explicitly resolves, first, how the project definition should be best designed so as to cope well with foreseeable changes in requirements in the future. Second, it uncovers which stakeholders will be responsible for funding the additional costs to build the options at risk, and to exercise the options in the future if the uncertainties resolve favourably. The champion and stakeholders may fail to achieve consensus around a design for evolvability strategy at this stage especially if capital resources are scarce or the stakeholders' planning horizons (which influence their discount rates) are sharply different. I argue, however, that an eventual failure to reach consensus does not diminish the value that a design for evolvability protocol can add to project front-end strategizing. In this situation, the champion should work with the stakeholders to document in the final output that further negotiations are needed to resolve uncertainties around (1) whether particular options should be built in; (2) who should incur the capital costs of those potential options if there is no disagreement across stakeholders that the options should be built in; and (3) who should incur the future adaptation costs if there is disagreement across stakeholders that the option should be built in. The final output should also include any plans to mitigate risks of costly adaptation in the future if the options are not affordable.

### 6.4.1 Recommend a Design for Evolvability Strategy

The first step of the final stage is to recommend a design for evolvability strategy, based on the analysis undertaken in the previous stages. The team has to agree collectively on: (1) a design concept which might (or might not) incorporate built-in options, (2) the extent of the design investment allocated to build the options, and (3) a funding strategy. The funding strategy should discuss the upfront costs at risk, the eventual adaptation costs if uncertainties resolve favourably and the option is built in, the adaptation costs if the option is not built in, and the option sponsorship. By clarifying the costs and potential benefits associated with the key built-in options in the concept design, the team is able to justify the investments required for building the options and agree on the source of funding. Overall, this process will offer the multi-stakeholder team opportunity to formally compare alternative design concepts and recommend one for implementation in light of available information about the future states of the world, affordability constraints in the present, and foreseeable adaptation costs in the future. In addition, the outcome of the process – a document spelling out the rationale as to why particular options were (or were not) built in the asset definition – will constitute evidence valuable to improve the fairness of any eventual future judgments on the quality of decision-makers' decisions. The senior members of project teams involved in the early design decision-making process are inevitable accountable for those decisions. To ensure fairness, it is important to also document the context in which decisions had to be made, particular in terms of the information and the capital resources that were available at the time.

### 6.4.2 Specify Design for Evolvability Checkpoints

The last step of the method to design for evolvability specifies design for evolvability checkpoints over the project design time. These checkpoints can be useful to interrogate the validity of assumptions made in the early stages as the design process unfolds. Checkpoints can be particularly relevant in capital projects where the front-end strategizing process may span over several years time until the project team succeeds to secure the capital to go ahead. They can also be useful after the project gets sanctioned by the funders and moves into design detailing and physical implementation. By periodically interrogating the validity of core assumptions, the checkpoints will offer project teams the opportunity to think as to whether the design strategy for the project should stay unchanged (or not) in light of new information. Terminating a project can carry intangible costs related to credibility and morale (Fichman et al., 2005) as managers can be personally vested in seeing their projects succeed. Thus, the proposed checkpoints might be especially important in a scenario where project teams are reluctant to change the design strategy for a project albeit radical changes in the environment that may put in questions whether the project should go ahead in its current design form, or go ahead at all in the most extreme cases.

## 6.5 Design for Evolvability Champion

The champion of design for evolvability is the title of the individual that should work with the multi-stakeholder project teams to ensure they understand and follow the sequence of steps spelled out in the previous sections. In other words, the champion is the subject-matter expert. The champion is more than a facilitator in charge of overseeing the quality of the design decisions made at the project front-end. I argue that the champion should be empowered by the project promoter to steer a group of legitimate project stakeholders to agree on a design concept that factors in both concerns of short-term affordability and long-term adaptability. By guiding the team into following the sequence of steps described above, the champion will help the team to coalesce their most likely heterogeneous views of the world and planning horizons into a design concept which all stakeholders will endorse as the one that needs to progress into the next design stage. The rationale underpinning this concept should factor in the team's understanding on foreseeable uncertainty so as to mitigate the risk for costly (if not prohibitive) design adaptation if the foreseeable uncertainties resolve favourably in the future. The champion of design for evolvability shall guarantee that the team addresses the difficult issues including: (a) the need to make investments in design flexibility at risk which can be particularly challenging to make in a context of scarce resources; and (b) the long-term risks particularly to the asset's operational longevity if built-in options are not affordable.

Admittedly, additional project costs are imposed by bringing in another member to the front-end strategizing process – the champion of design for evolvability – who needs to be trained in terms of options logic. Additionally, the formalization of a design for evolvability framing requires organizations to develop new protocols that fit with their own capital development processes, educate their teams accordingly, and train people to be agents of the change. Capital organizations such as NR often hire professionals to facilitate front-end multilateral discussions, but these facilitators seldom have domain knowledge of capital projects. I hypothesise that the costs of introducing the new framing can be marginal compared to the potential benefits the champion of design for evolvability can proportionate. As designed in the proof-of-principle, the training is focused solely on the qualitative understanding of the key variables and relationships in options logic, purposely avoiding the complex options pricing models which can be overwhelming for people without strong mathematical training. The next chapter discusses the two-group controlled experiment that was set up to test the underlying proposal that a formal design for evolvability protocol adds value to the front-end strategizing of capital projects.

# 7 A Two-Group Controlled Experiment: Lab-based simulation of the Salford Crescent Redevelopment Project

This chapter describes and discusses the two-group controlled experiment undertaken to validate the new framing to design for evolvability. It starts with the importance of theory-oriented experimental research on management and organisation field and on this particular research more specifically. Subsequently, details of the Salford Crescent Redevelopment project used to simulate the front-end strategizing process along with the details of the projects roles are presented. The details presented here are relevant to the simulation only, and they complement the previous discussion of this particular project held in section 5.2.3. Finally, this chapter discusses the data collected through the simulation exercises ran with graduate-standing students. Results of the control and experimental groups are analysed and compared to verify the usability of the design for evolvability framing to the front-end strategizing process.

## 7.1 The value of theory-oriented experimental research

Theory-oriented experimental research has long been established and well accepted as a useful method to further theoretical understanding in various disciplines such as psychology, industrial organisation, and economics (Anderson, Lindsay, & Bushman, 1999; Croson, Anand, & Agatwa, 2007). Studies of the correspondence between results from lab-based experimental research with observational research (developed from empirical data derived either from archival or primary sources) have found little support for claims that lab-based experiments produce research that is low in external validity (Anderson et al., 1999). Recent calls have been made for management and organisation scholars to undertake more lab-based experimental research as a means to complement observational (empirical) research (Croson et al., 2007). Both experimental and observational research offer routes to help develop, test, and advance theory. In the management field, lab-based experiments offer a research method which involves collecting primary data from individual decision-makers who face real payoffs from their responses (Croson et al., 2007). Two-group controlled experiments allow comparing how changes in specific variables influence the participants' behaviours and outcomes, the dependent variables, as the researcher varies the independent variables from the experimental to the control group. In summary, the most salient advantages of lab-based research that make it a useful complement to empirical and deductive research are (Croson et al., 2007): (1) experimental research can provide relatively clean, observable dependent measures as it allows to control for sources of variation, e.g., individual differences in risk preferences, or levels of experience; (2) it allows to control for confounders that could undermine the internal validity of the research such as contextual variables; (3) it enables to construct laboratory conditions that are replicable in order to test propositions and theory's point-predictions; and (4) it enables to establish causality that is hypothesized from existing research through two-group controlled experiments more conclusively than empirical research would allow to.

## 7.2 The purpose of a lab-based simulation of front-end strategizing

In this research, the empirical studies revealed systematic use of options logic in capital project front-end strategizing, but they also showed that practitioners invariably used options logic intuitively. The analytical assessment of a project front-end strategizing process in turn revealed the inadequacy of any attempt to use real options pricing to support relatively mundane design decisions at project front-end strategizing. Both insights were relevant, and provided the motivation to explore whether formal real options reasoning based on a qualitatively rather than quantitative approach could add value to front-end strategizing. To address this question, a lab-based experiment was set up as a complement to the empirical studies. Action research (Argyris, Putnam, & Smith, 1985) could have been an alternative route to investigate this question. However, the timescales typically associated to negotiate with an organisation an action research programme and get it implemented made it an inadequate methodology to support a hybrid research method. Of course experimental research has some limitations in terms of external validity, e.g., the degree to which the relationship between the independent and dependent variables can be generalized to real-world settings (Campbell, 1957). These limitations are discussed after the analysis of the experimental results (section 8.4).

The main purpose of the lab-based experiment in this study was to investigate a theoretical relationship among variance in the level of formalisation of the adoption of options logic in capital design decision-making (independent variable) and the overall performance of project front-end strategizing (dependent variable). The interest here was to investigate effects to performance in terms of the quality of both the product and the process. The design of the exercise at the heart of the experiment enabled to simulate a capital project front-end strategizing environment and to isolate and vary the independent variable. The ability to vary the independent variable is essential to undertake two-group controlled experiments. If the experiment allows observing differences in the dependent variable as specific parameters of the independent variable are varied, the researcher can conclude that the independent variable caused observable differences in the dependent variable (Campbell, 1957). Specifically, the exercise allowed to compare the performance of the front-end strategizing process where the project teams adopted a formal design for evolvability framing (experimental groups) against the performance of a front-end strategizing process where the project teams were not directed to use any procedural tool (control groups).

To play the exercise, groups of six (control groups) or seven (experimental groups) participants need to be assembled first into project teams. A week before the exercise session, each participant is allocated the role of a different project stakeholder and given detailed briefs that offer information about the simulation, the purpose of the role, and background information about the stakeholder organisation. Taken together, these documents ensure that each participant builds a knowledge base essential to play competently the role s/he was assigned to. The assimilation of the role does not require a specific technical background. The documents also provide pointers to more background information that participants can access online to learn more about their parent organisations. Just like in the real world, however, making the pointers available does not provide a guarantee that people will actually read it. The exercise is set up in a way that simulates the ‘fuzzy’ nature of the capital project front-end strategizing, which involves multilateral negotiations across stakeholders with sharp differences in priorities, knowledge bases, technical capabilities, planning horizons, and the wherewithal for funding the project. The efforts to control for the experiment conditions and to homogenize the participants’ knowledge base prior to starting the exercise help to control for the confounding effects of other dependent variables on performance – a condition necessary to ensure internal validity.

Specifically, the exercise simulates a project environment in which some stakeholders may *not* be in a position to contribute to fund a design concept that meets their needs. Other stakeholders may have more financial resources, but may be reluctant to deploy them to fund functional elements that they did not demand. Tensions inevitably surface as the stakeholders with limited resources are bound to believe that they are legitimately entitled to demand particular functional elements even if they are not sure about the extent to which these elements will be needed as they acknowledge their requirements may evolve over time. The exercise thus forces the project team to address collectively the inevitable tension between short-term affordability and long-term adaptability at the heart of front-end strategizing capital projects. The overall goal is to achieve a multilateral agreement on both a concept design with which the project could progress into the next design development stage, and on a funding strategy for that concept. To solve this problem, groups of graduate-standing students (MSc and MBA) were asked to participate. The design of the exercise was grounded on fine-grained empirical data of the front-end strategizing process for a real-world contemporaneous capital project: the redevelopment of the Salford Crescent railway station, a dangerously overcrowded station in the North West of the UK (also presented in section 5.2.3).

## 7.3 Details of the Capital Project Informing the Simulation Experiment

The £12M Salford Crescent Redevelopment project aims to improve the existing platforms and the overall layout of this railway station originally built in 1983. The station is located near the University of Salford, which had the majority of its building stock constructed in the 1960s and 70s. Overtime, passenger demand to use the railway station had increased dramatically especially due to the expansion of the University which grew to approximately 20,000 registered students and near 2,500 staff members in 2011. In the recent past, the university had also embarked on an ambitious capital programme to improve and expand its campus. As a consequence of the increase in passenger demand, the 1983 station building was in 2009 already struggling to cope with the levels of usage. The volume of patrons at the station had grown from 0.58 million passengers in 2004/2005 to 0.73 million passengers in 2007/2008 (GMPTE, 2009). By 2009, it was undeniable that the lack of space for circulation at the platforms at rush hours had been posing serious risks to passenger safety, a point made clear in the regeneration appraisal of the station and scoping visit reports conducted by NR. These high levels of patronage, and the risks to passenger safety associated with them, led to concerted calls from multiple stakeholders for an urgent redevelopment of the railway station, a higher order objective that was formally articulated in the NR's Route Utilisation Strategy (RUS) developed in 2007 (Netwrok Rail, 2007). The rearrangement of the furniture and the extension of the platforms were deemed two priorities essential to mitigate the risk of a station closure by 2015, when demand was expected to reach one million people every year.

For the front-end strategizing process to be perceived as successful in the eyes of its key stakeholders, its outcome needed to meet a range of higher- and lower-order objectives. The higher-order objectives are a key motivation to engage the key stakeholders in capital projects, and create goal congruence at the highest level. Hence, all stakeholders were in agreement that the project concept design needed, first, to satisfy the DfT high-level output specification (HLOS) metrics to meet the security and safety requirements for the industry; and second, the concept design needed to minimise overcrowding on the platforms at peak times in order to increase the overall performance of the local railway network. From the perspective of the main private train operator, Northern Rail, there was also an aspiration that a renewed station could provide a catalyst for the railway industry to start running direct Calder Valley[24] services to and from Salford Crescent. The private operator, a company that was also responsible for operating the train station, was unsure as to when a business case could be made for starting to run a direct service. Surely, Northern Rail was not going to invest in direct services until the Salford Crescent had been modernised. For the time being, Northern Rail's plan was to continue to run an alternative primary route with indirect services through Stalybridge (with generally higher line speeds and less restrictions) in conjunction with First TransPennine Express (FTPE). Nonetheless, Northern Rail reckoned that an alternative direct route could become a profitable operation in a few years time since Salford Crescent was becoming a crucial piece of the regional railway network.

Two second-order objectives that the project could eventually meet were on the negotiation table. First, the project could deliver a third platform, which would add enough capacity for the railway station to cope with a projected growth in demand over the next three decades. This scenario would increase the costs that Northern Rail was currently incurring to operate the station. Unsurprisingly, the idea had the backing of the University. It was also warmly received by numerous parties including the transport authority Greater Manchester Passenger Transport Executive (GMPTE), the Salford council, and the Salford Urban Regeneration Company (URC). URC was a company set up in 2005 to provide leadership to a £1bn regeneration plan for Salford, leveraging public grants from the North West Development Agency and the Homes and Communities Agency. This second-order objective for the railway development project was formally specified in NR's RUS, which even discussed a scenario that proposed relocating the station to

[24] The Calder Valley line is a secondary route between Manchester and Leeds, serving the intermediate towns of Rochdale, Todmorden, Hebden Bridge, Halifax and Bradford as well as several other smaller stations. See appendix E for route map.

make it easy to build four platforms. The idea of relocating the station was short-lived, and abandoned right at the start of project front-end strategizing due to its costs and the need to keep the station near the university. Another second-order objective was being promoted by the Salford Council and the URC. Both parties were lobbying to ensure that the capital investment in the railway station delivered a landmark station building, i.e., a bespoke design that would enhance the appearance of the station and promote its usage rather than a more cost-effective pre-fabricated solution.

Faced with this set of first- and second-order objectives, the project decision-makers had to agree multilaterally on a design concept and who was going to pay for what functional elements in that design concept. More specifically, decision-makers had to agree which requirements should inform the design concept, whether some requirements could or should be excluded from the project remit, and define a design concept that would meet the selected requirements. These decisions had to be taken collectively based on a comparative analysis of the potential perceived benefits of meeting the different requirements versus the associated capital and operational costs that the different stakeholders would need to incur to meet those requirements. Front-end strategizing this project was difficult as the stakeholders needed to make decisions based on limited information and under uncertainty about the future. In addition, the organisations that could most benefit if the design concept met a particular requirement were not necessarily the ones with the wherewithal to provide the additional funding needed to meet that requirement.

The exercise at the basis of the experiment simulated the voices that six different project stakeholders brought to the front-end strategizing process: three representatives from Network Rail and three external stakeholders. The selection was not exhaustive but rather sought to capture the most salient voices based on the analysis of archival documents and attendance of projects meetings. Network Rail was a key stakeholder. It was both the owner of the station and the organisation that owned and had developed the route utilization strategy. This position meant that NR was the only organisation in a position to apply for grants that the Department of Transport (DfT) was making available under the National Stations Improvement Programme (NSIP). This programme was a joint rail industry initiative involving NR, Train Operating Companies, and the DfT aimed at improving 150 medium-sized stations in England and Wales. It had an overall budget of £150M to fund project grants during the Control Period 4 (CP4). A project as Salford Crescent was well aligned with the remit for the NSIP. NR also had the technical and commercial capabilities that were needed to develop a successful bid to the DfT and oversee the design and construction works once the government committed to fund the project.

As a very large organization, three departments of the NR infrastructure division got involved on front-end strategizing the Salford Crescent project: the commercial department, the engineering department and the project management department. NR commercial sponsors were in charge of intermediating the negotiations between NR and business partners such as Northern Rail in order to satisfy the interests of the partners without compromising the NR's commercial interests. NR engineers provided the technical expertise to assist the project team on defining a design concept commensurate with the funding available and NR strategic plans. NR engineers were also in charge of liaising with the surveyor team to verify their assumptions around site conditions, costs, and project timescales. Finally, NR project managers had general knowledge about railway projects, specific knowledge about the Salford Crescent project; NR project managers were ultimately responsible for ensuring that the agreed design concept could be delivered on time and within budget.

Another key stakeholder simulated in the exercise was Northern Rail, the private train operator that operated the Salford Crescent train station, and some train services running through station. The current franchise contract for the station was due to end in 2014. It would depend on the government whether this contract with Northern Rail would be extended beyond this time. First TransPennine Express

(FTPE) was the other private train operator operating trains at this station[25]. Only Northern Rail's voice is simulated in the exercise since the FTPE's requirements and concerns were not significantly dissimilar to those from Northern Rail. A third key stakeholder simulated in the exercise was the Central Salford Urban Regeneration Company (URC). In many ways, this organisation set up in 2005 saw itself as a legitimate project customer since it was driving a £4bn capital programme to regenerate Salford in partnership with the Salford City Council. Funded by central government grants, URC was an influential player. Amongst its list of achievements, URC had played a pivotal role in bringing MediaCity, the new home for the BBC and ITV, to the Salford Quays and was also buying parcels of land in preparation for revamp of Salford's historic area not far from Salford Crescent. Unsurprisingly, the Salford City Council was also interested in this project from a planning and highway perspective. The Council was using its own funds to support the development of a shuttle bus connection from Salford Crescent to Media City in Salford Quays. The council voice, however, was not included in the exercise because it was largely aligned with the URC's voice. Moreover, the Salford City Council had limited funding capabilities to provide financial support[26].

A fourth key stakeholder simulated in the exercise was the University of Salford. The University had its main campus located on both sides of the station. This project was of strategic importance for the University as it interfaced with its own capital plans to redevelop the campus. Finally, GMPTE had important stakes in this project. GMPTE was interested in seeing this project reaching completion mainly to ensure the integration of the upgraded Salford Crescent station with other transport

[25] Northern Rail operated services to Bolton, Clitheroe, Wigan, Kirkby, Southport and Blackpool North, whilst FTPE operated services to Barrow-in-Furness and to Oxenholme, Windermere and also Blackpool North. Appendix F shows the TOCs franchises around the Salford Crescent area.

[26] The Council financial position deteriorated further with the downturn in the UK economy, and in 2012 the Council slashed 400 jobs as part of a £24M cuts package imposed by the government (Manchester Evening News, 2012). However, this event is post 2009 and therefore not included in the exercise.

modes, such as the enhanced connection with bus services on the nearby A6 highway and the connection with Media City. The GMPTE's role, however, was not simulated in the exercise. GMPTE was primarily interested in being kept abreast of the project concept design and timescale but from the onset expressed some reluctance to fund the investment and to have a more intervenient role in the concept design discussions provided they were in agreement with GMPTE plans to build a new bus lay-by nearby.

Table 7.1 describes the main objectives of the six stakeholder roles that were simulated in the exercise. A week before starting an exercise, these roles were allocated to the students. Students were given additional information in order to help them build understanding and knowledge both on the specifics of the role they were assigned to, as well as on the parent organisation. In addition, all students received a generic design brief explaining in detail the goal of the exercise and the underlying rules. The students were strongly encouraged to read the information. To incentivise them, the documented outcomes of the exercise (a minute of the meeting and a strategic recommendation) were factored in the students' final evaluation for the course.[27] This process of information feeding and of setting the rules of the exercise was important to level the knowledge baselines of the students across the different groups, and create a level playing field across teams. This was important to ensure that the outcomes of the different exercise runs could be compared irrespectively of the differences in the educational backgrounds of the students and in their years of professional experience.

[27] Exceptionally, some groups were not asked to submit documented documents, but rather to participate in a follow up debriefing exercise led by the instructor.

**Table 7.1: Project stakeholders objectives and information hand outs**

| Stakeholder role | Main objectives for the front-end strategizing process | Hand outs provided | |
|---|---|---|---|
| | | Role-specific information | Ancillary information |
| NR Project Manager | 1. Deliver the project on time and within the budget<br>2. Ensure the concept meets the DfT High Level Output Specification<br>3. Ensure the concept fits with the NSIP policy | Document containing growth forecasts, costs estimations, budget outlays, and DDA requirements | NR Route Utilisation Strategy for the North West |
| NR Project Engineer | 1. Ensure the concept meets the railways industry technical standards and regulations<br>2. Ensure the project concept can be delivered with a reasonable budget and timescale when compared with projects with similar scope | Document containing technical specifications such as platforms length, signalling, possessions, and electrification | NR Route Utilisation Strategy for the North West |
| NR Commercial Sponsor | Ensure the concept meets the external stakeholders' interests, particularly those of the franchised train and station operator, without compromising the NR commercial interests | Document outlining railway bottlenecks, passengers movements, and main stakeholder interests | NR Route Utilisation Strategy for the North West |
| University of Salford | 1. Ensure the concept is aligned with the University's campus master plan<br>2. Ensure the concept guarantees ease of access to the campus<br>3. Ensure the concept encourages people to sustainably commute | Document outlining the university's regeneration plan, student growth, and students needs | University Campus master plan |
| Regeneration Agency – Central Salford URC | Ensure the concept produces an aesthetically pleasant station building ('landmark building') to support the local socio-economic development | Document explaining how the regeneration company intended to transform Salford and highlighting interdependent projects | Vision and Regeneration Local Framework |
| Station and Train Private Operator – Northern Rail | Ensure that the concept guarantees short-term revenue protection, whilst improving the reliability and friendliness of the train services and station | Document explaining the main operational requirements for the station | Station operator response to the NR North West RUS |

The multi-stakeholder nature of this railway station redevelopment scheme created a challenging front-end strategizing process. It required the different organisational representatives to negotiate their preferred objectives and priorities, make compromises and trade-offs, and ultimately agree on a design concept in light of the funding that could be collectively brought to bear to fund the project within a reasonable timescale. Of course, the exercise could not simulate the whole complexity of the real-world project, and some simplifications had to be made. The exercise simulates a relatively stable environment from an institutional perspective as it only covers the last value management meeting for the front-end strategizing as part of the NR's capital development process. This meeting was aimed at crystallising a design concept and funding strategy in order for the development scheme to progress into the next project phase. For this meeting, the groups had to discuss and compare the capital and operational costs as well as potential benefits associated to six alternatives, some of which proposed to design options in the concept. These alternatives, summarised in Table 7.2, aimed to provide a basis for the conversation, but the groups were not precluded to recommend a strategy that did not fit with one of the alternatives.

**Table 7.2: Summary of the alternative concepts for Salford Crescent Redevelopment project**

| Description of the Alternative | | Approximate Cost | Options built-in | Salient advantages to particular stakeholders | Salient disadvantages to particular stakeholders |
|---|---|---|---|---|---|
| A | Abandon the project | £200K (sunk cost) | - | For NR: No additional investment is required. | Apply to all parties: Huge risks to reputation if accident happens; operational costs likely to increase. |
| B | Lengthen the two island platforms in order to accommodate 6-car train operations | Yet to be estimated | - | For Northern Rail: it maintains short-term revenue protection;<br>Apply to all parties: it creates opportunities to run more train services. | Apply to all parties: Does not eliminate the overcrowding problem and the imminent closure of the station. |
| C | Add a third platform that could accommodate 8-car train operations | £2.8M | - | Apply to all parties: capacity increase of the station will create opportunities to run more train services through the station. | For Northern Rail: Does not maintain revenue protection in the short-term as it creates multiple access points to the station) and involves disruptive possessions;<br>For NR works on signalling and tracks to add third platform require additional £20M that are not covered by the NSIP grant. |
| D | De-clutter and extend the island platforms to accommodate 6-car trains, and move the access to the station to southern end | £7.5M | Transform station into a landmark building; add a third platform in the future | For all parties: Eliminate overcrowding and increase the capacity of the station to a level that will comfortably accommodate projected demand increase up to 2025. | For Northern Rail: It increases operational costs as it needs to hire an additional dispatcher and maintain associated accommodation; it also involves some disruptive possessions. |
| E | De-clutter the island platforms and move the ticket office to east or west side | £4.9M | - | For NR, Northern Rail: project implementation requires minimal possessions. | For Northern Rail: It does not maintain revenue protection as it creates multiple access to the station);<br>Apply to all parties: it fails to meet the projected passenger growth until 2025 and prohibits landmark building aspiration. |

| | | | | | |
|---|---|---|---|---|---|
| F | Add a third platform, de-clutter and extend the island platforms, and move access to southern end of the island platforms | £10.3M | Transform station into a landmark building in the future | Apply to all parties: Eliminate overcrowding and keep the station at a comfortable level until 2045. | For NR: works on signalling and tracks to add third platform will require additional £20M funding not covered by NSIP grant;<br>For Northern Rail: works will require disruptive possessions; operating final solution will require additional dispatcher and associated accommodation. |

In contrast to the simulated environment, front-end strategizing in the real-world was a significantly more protracted process during which the environment continued to evolve. Front-end strategizing effectively started around 2009. Only on 15 December 2011, NR finally submitted the planning application to erect a new station building, together with a new footbridge with lift tower and step access to the existing platform. Few months later, on 30 April 2012, NR submitted a proposal asking approval for an extension and alterations to the existing platforms, involving the removal of the existing platform buildings and access ramp and construction of new platform buildings and structures. In August 2012, NR was still waiting for the Council to confirm the planning application was compliant with numerous conditions. Since October 2011, the Council had been working on the consultation of a draft document proposing a new non-statutory planning framework (that would become a material consideration in the determination of planning applications) for the Salford Crescent area that included new residential, offices, and leisure development. The draft framework stated: "The Crescent is Salford's principal higher education and cultural area and is a priority transformation area for the City Council. There are opportunities to deliver new commercial, residential, visitor and University related developments to take advantage of the Crescent's existing fine heritage and proximity to the regional centre."

In the early days back to 2008/09, DfT, NR, Central Salford URC, the Council, and GMPTE were all lined up as potential funders. GMPTE gradually backed away from that position after political changes in central government and the financial crisis conjointly led to drastic cuts on the budgets of many public bodies. By 2011, GMPTE had already folded into a new organisation, the Transport for Greater

Manchester (TfGM), following major changes in the organisation of the local transportation authorities. During the front-end strategizing period, it also became increasingly clear that Central Salford URC was going to be wounded up. In November 2010, the URC chairman announced the company would close in 2011 after losing its 2 major funders. These changes in the environment are not unusual in capital projects which can take many years to front-end strategize due to the complex institutional nature of the environment affected by the project. Still, the DfT NSIP funding remained available and NR decided to go ahead with the project. Alternative D (de-clutter and extend the island platforms and move the access to the southern end) was selected as a result of the front-end strategizing process. NR started working on the planning application process for the station redevelopment project in December 2009 with a view to undertake the construction from November 2012 to July 2014. The planned project completion date was the end of December 2014. In the NR environment, the Salford Crescent project was categorized as a medium-sized project given that the estimated project costs were inferior to £50M, and the implementation period was inferior to two years.

## 7.4 Generation of Experimental Data

Over a 12-month elapsed time between October 2011 and October 2012, teams of students were assembled to play the simulation exercises as part of the experimental research study. Two types of project teams were set up: the experimental and the control teams. The students in the experimental groups received the support of a NR design for evolvability champion, whereas those in the control group had to get their act together on their own to mimic the observed real-world processes. Succinctly, the role of the champion was to educate the team about the implications of ruling in and out provisions to build options from the concept design. The champion was tasked to highlight to the team that making a relatively small investment upfront could prevent potential problems later, provided the investment was affordable and sensible. The champion was also tasked to educate the team on real options reasoning, and to encourage the team to adopt a design for evolvability framework to support design decision-making. This framework, presented in detail in Chapter 6, offers a step-by-step methodology that proposes a way to formalise the use of options logic to resolve concept design at front-end strategizing. If teams adopt the structured process in the framework, they will be faced with explicit points they need to discuss: first, which design provisions to cope with foreseeable uncertainties should be designed in the concept of a new asset with a long operational life; and second, how to distribute the capital costs of those provisions (and crucially of eventually exercising the options if the uncertainties resolve in a favourable way) across the different stakeholders. In all other respects, the experimental and control groups faced similar conditions, and they received exactly the same information before the beginning of the exercise. In total, 17 groups took part in the exercise, including nine control groups and eight experimental groups.

## 7.5 Analysis of the Simulation Results

### 7.5.1 Conceptual framework to assess the dependent variables

To rigorously compare the overall performance of the experimental group against the performance of the control group, I adapted the ISO (1998) guidelines for assessing the usability of engineered processes. These guidelines define usability as “the effectiveness, efficiency, and satisfaction with which specified users can achieve goals in particular environments”. I measured the usability of these processes by building a set of codes to analyse and compare qualitatively the outcomes produced by the teams in the two groups. To evaluate effectiveness, I used three codes that capture three conventional measures of assessment (Hornbæk, 2006; Sauro & Kindlund, 2005): (1) clarity, i.e., the extent to which the outcomes are concise and document the assumptions; (2) comprehensiveness, i.e., the extent to which the outcomes resolve the key dimensions of the problem including the concept design and the funding strategy; and (3) buy-in, i.e., the extent to which the outcomes meet the interests of all the affected parties.

To evaluate efficiency, I also used three codes based on traditional measures to assess efficiency (Hornbæk, 2006; Sauro & Kindlund, 2005): (1) input rate, i.e., the extent to which all the project participants contributed to the discussion; (2) communication effort, i.e., the extent to which the project participants shared their interests and concerns; and (3) mental effort, i.e., the extent to which the project participants shared ideas and exhibited creative thinking in overcoming obstacles. I did not measure process time, another measure of efficiency, as the duration of the exercise was constrained by the set-up.

To assess satisfaction, I used the Lewis (2002) Post Study System Usability Questionnaire (PSSUQ). This standard questionnaire computes satisfaction as an aggregate construct of three dependent variables – perceptions of system usefulness, information quality, and interface quality. Each dependent variable in turn is an aggregate construct of an independent set of statements. In total, the questionnaire consists of 19 statements. The students were asked to qualify each of those statements through a Likert-scale, indicating whether they strongly agree with it (1), strongly disagree with it (7), or whether their perception is better represented by a value somewhere in between these two extremes (2-6). Appendix B reproduces the questionnaire.

### 7.5.2 Analysing the simulation results

The qualitative analysis of the experimental results suggests that the experimental groups overall performed better than the control groups. Table 7.3 provides a summary of the findings and illustrates the discussion that follows. The qualitative findings suggest that the groups unaided by the champion were more likely to struggle to build a common ground during the discussion. As a result, these groups tended to run out of time to resolve the key decisions needed to produce a complete outcome. Put differently, the findings suggest that the experimental groups were systematically more efficient in the front-end strategizing process and that efficiency in turn enabled them to produce more effective outcomes. In contrast, the performance of the control groups from an efficiency perspective would systematically show instances where individual behaviour was shaped by a greater emphasis on optimisation of the individual's position. As a result, the teams in the control groups tended to exhibit less willingness to compromise and search for acceptable trade-offs. They also showed more difficulties to build common ground and understand each other. These conditions tended to make the multilateral negotiation process more cumbersome and difficult for the control groups. Because the time to resolve the exercise was constrained, the control groups were more likely to run out of time to develop comprehensive outputs and hammer out any related deals. For example, one Northern Rail representative in a control group still insisted on abandoning the project by the end of the process since the funding issue remained unresolved ("*why not [abandoning it]? I don't see any point in me investing money*"). This suggests that the student failed to appreciate the ultimate goal of the exercise – the need to urgently resolve the overcrowding problem at the platforms – due to divergent interests with the other participants in regards to funding issues. Such a radical posturing was never observed in the experimental groups.

**Table 7.3: Qualitative comparison of the usability of the front-end strategizing process between the two groups**

| Usability of the front-end strategizing | Control Group | Experimental Group |
|---|---|---|
| Efficiency | Low<br><br>Teams experiences amplification of conflict between divergent interests due to poor communication.<br><br>Teams tended to engage in unstructured and unguided debates, making it harder to reach an agreement on funding issues. | High<br><br>Teams more likely to demonstrate creative thinking and ingenuity.<br><br>Teams generally managed to engage in timely and productive exchanges of information. |
| Effectiveness | Moderate<br><br>As the teams ran out of time (as a consequence of the lack of efficiency), they struggled to pin down their strategic recommendations. | High<br><br>Teams normally managed to resolve major issues including which stakeholders were more likely to benefit from particular options, who should pay for them, and who had the wherewithal to provide the additional funding.<br><br>Teams were receptive to borrow the options logic constructs to frame the discussions. |
| Satisfaction | Moderate<br><br>Some participants demonstrated their discontentment with the time-consuming process and with pointless conversations. | Moderate<br><br>Participants did not perceive the design for evolvability proposition as unnecessarily redundant and bureaucratic. Some of them even highlighted the usefulness of having a design for evolvability champion. |

## Insights on efficiency

Almost invariably, the experimental groups heeded to the design for evolvability champion and were open to borrow the lexicon and reasoning from options logic to structure the discussions. Table 7.4 summarises evaluation data on the efficiency of the front-end strategizing process for the two types of groups. Experimental groups did not push back on the agenda of the champion. As a result, they tended to be more efficient in sharing information and in creating space in the discussion to think creatively and devise solutions that could coalesce very different needs. The experimental groups successfully drew on the design for evolvability framing to structure their conversations. One group, for example, used the framing to structure a discussion around the extent to which a landmark building could be funded. In these formal design for evolvability discussions, some participants could offer ideas that were arguably unrealistic. For example, the group considered the idea of seeking funding from an European body, although no one knew which body should be. Notwithstanding the weaknesses of some ideas, the data shows that the discussions tended to be efficient. The framing spurred the teams to think through alternative scenarios that might affect design requirements. This made the teams more efficient given that the information about the project was spread across the various members of the team. Put differently, the framing enabled the teams to debate the design alternatives at front-end strategizing, an important practice to ensure the project strategy can be aligned with the resources and time available, and can adequately cope with a constantly changing environment (Morris, 1994).

**Table 7.4: Excerpt of comparative analysis of front-end strategizing process efficiency**

| Category of efficiency | Control Groups | Experimental Groups |
|---|---|---|
| Input rate | Low<br>*"We didn't witness strong debate on stakeholder issues, which is a pity as the experiment is designed to tease out conflicting points" [University rep]*<br>*"The task was not easy. The level of institutional support received was very low" [NR Project manager]* | High<br>*"The participants facilitated options-logic thinking by sharing their strategic plans" [Regeneration agency rep]*<br>*"It was in my interest that the most ambitious alternative was considered and I started to negotiate it with others" [University rep]*<br>*"Nobody else had that information [extra costs for building a third platform]. If I hadn't mentioned that, for sure option (f) would have been selected" [NR Project engineer]*<br>*"In the beginning, we shared our interests, responsibilities, and also our lack of means to finance the project" [NR Project manager]* |
| Communication effort | Low<br>*"With the involvement of multiple agencies, it wasn't an easy task to agree on any common point" [NR Commercial sponsor]*<br>*"It's not clear to me whether we should have opened our role details to the others...I still don't have any certainty about the other players' intentions" [Regeneration agency rep]* | High<br>*"The champion asked everyone to mention and justify the most viable options...he was in charge of controlling the correct flow of the meeting" [NR Project engineer]*<br>*"It was an efficient exercise because everybody had the opportunity to talk and express their point of view" [University rep]*<br>*"It was remarkable that everyone defended their position, but also looked for an effective resolution" [NR Project engineer]* |
| Mental effort | Moderate: Limited evidence of creative thinking<br>*"The contribution and commitment of the team members were different. Some only had a basic idea of the project, and it was easy for them to get lost throughout the discussion" [University rep]* | High: Evidence of creative thinking<br>*"I [University rep] didn't want to commit financially for the future development, but stakeholders demanded my commitment, and I agreed to it only if I increased the number of students significantly"*<br>*"I recommended a contribution from a group of stakeholders such as Northern Rail and also private investors. For example, I recommended a kind of commercial centre in the new building and also outside the building, so they could provide equity. I also recommended contributions of banks, loans, and also making your bank to provide lower interest rates" [NR Commercial Sponsor]* |

The experimental results also suggest that the design for evolvability framing was useful to ensure the timely exchange of information. The exercise was set up in a way that only the NR project engineer in the team was actually aware that adding a third platform would make the capital costs escalate. The cost of constructing a third platform seemed deceptively affordable (less than £3M) because it did not account for the cost of the pre-requisite works to rebuild all adjacent railway tracks and to modify adjacent signalling that NR estimated to exceed £20M. The findings show that the experimental groups were systematically successful to get this information shared right at the onset. This was fundamental to ground any decision around whether to design in a third platform, just design in safeguarding provisions so as not to destroy the economic value of this option in the future, or do nothing about this option. The excerpt of the meeting of one of the experimental groups shows an example (Figure 7.1). The early contributions from the champion to elucidate the focus of the discussion have encouraged the group members to start sharing their information at the beginning of the meeting (the transcript reproduces the conversation 20 minutes after the start of the meeting). It also triggered a debate where participants questioned about advantages and disadvantages of immediate versus future needs.

**DfE champion:** alternative C is where it starts to get complicated. This alternative you have options within the design concept. So in the first two alternatives, you have no extra choices. It's only "yes" or "no", but here you've got "yes, but we also need to…" So you can have the third platform and also have the option to extend it in the future. So what we need to consider here is: first, do we want a platform? And second, do you want the extension? And the extension might be in 25 years, things might have changed. So you need to capture what you think will be the best for now and what potentially will be the best for the future.

> **Comment [GB1]:** Reminds the group what needs to be factored in the design decision-making.

**Private operator:** well for us that's a good alternative, but not for now. Why? First, because we will not achieve revenue protection, we will have multiple access points in different parts of the station. Also it increases our operational costs, because we need more staff in different parts of the station. We think it might be a good alternative, but only in the future. Nowadays, we don't think it's necessary to apply all those changes in the station.

**Project manager:** can you further clarify why it's going to increase costs for you?

**Private operator:** because we need more staff in different parts of the train station as we have multiple access points. We will not going to achieve revenue protection if we don't do it, because people will get to the platform through different ways.

> **Comment [GB2]:** Justifies why adding a third platform is not aligned with private operator immediate needs

**DfE champion:** is that a ticketing problem?

**Private operator:** yeah

[…]

**Project engineer:** just to add on private operator's comments. The cost of the platform is reasonable, just £3M roughly. But we need some adjacent works such as modifying signalling system and tracks. And that costs much more.

**Private operator:** how much is that?

**Project engineer:** it's about £20M.

**DfE champion:** that's a significant additional cost.

**Private operator:** yeah it's basically very expensive, because it's £20M to the initial £2.8M. I don't think we can afford that.

> **Comment [GB3]:** Group becomes aware early in the discussion of the adjacent works to add a 3rd platform

**Figure 7.1: Excerpt of the transcript of the discussion held by an experimental group**

An exception in the ability of the design for evolvability framing to improve the efficiency of the process occurred with one experimental group. In this case, the champion failed to adequately perform the tasks built in the role for which he had received training. As a result, the performance of this group was not that dissimilar to that of the control groups. The data suggests that this exception can be explained by a poor fit between the nature of the champion role and the personality of the student allocated to that role. Arguably due to shyness or lack of confidence, the student hardly intervened in the discussion process to the dismay of the other group participants:

> "Even though the champion of design for evolvability was appointed with this task [facilitating the meeting], this did not occur" [regeneration agency rep]

> “The champion should have acted as a mediator, but remained silent most of the time” [NR project engineer]

> “For the role to be effective, it has to be taken up by someone with a personality fit, broad knowledge of the problem and of the role. In the simulation, unfortunately, this was not really the case. The role was taken by a rather calm, shy person with a lack of understanding of his role, making the costs higher than the benefits” [NR project manager]

In fairness, the champion did raise a number of issues that followed the training he received. In a few occasions, the champion intervened and managed to trigger the conversations that he had been precisely tasked to steer. However, he did it in a timid as opposed to assertive way. He also shied away from using the design for evolvability framework to guide the design discussions. For example, the champion stepped back from the conversation right after asking timidly if the private train operator was in a position to fund some of the desirable options. The conversation only did not die at this stage because the NR commercial sponsor took the initiative to follow up and queried the private train operator if they could eventually contribute to fund the landmark building (Figure 7.2):

**Private operator:** I don’t feel adding a third platform is a solution. Option (d) – de-cluttering platform, extent island platform and move access to southern end – suits my interest the best... we also want a station that is architecturally nice.
**NR project manager:** OK, the building should be pretty in your opinion?
**Private operator:** yeah!
**DfE champion:** are you planning to support us with some funding too?
**Private operator:** I’m more like a lessee. We’re working on the operation cost. I don’t think we would want to provide capital investment.
**NR project engineer:** does anyone have questions for him?
**NR commercial sponsor:** you said you [station operator] want a landmark building, right? And you aren’t going to pay for the capital investment of that. My point is if you aren’t paying for the specifications that you’ve set up, that [landmark building] won’t be possible!
**Private operator:** I’m not asking for something that’s different. I’m asking for a simple, basic thing…
**NR commercial sponsor:** [a simple, basic thing] that requires. £3.5m. And you are saying you don’t have the fund, right?
**Private operator:** right
**NR commercial sponsor:** but you’re the one who will benefit the most from that.
**Private operator:** I don’t know. I currently operate 462 stations. This project is a necessity for the city. I’m not the one saying that I want this and that.

**Comment [GB1]:** DfE Champion initiates the debate on funding, but remains silent subsequently

**Comment [GB2]:** NR commercial sponsor explores who should be paying for a landmark building and why

**Comment [GB3]:** The lack of participation of the DfE Champion compromised the efficiency of the meeting. Other participants had to come up with an informal structure to debate the problem.

**Figure 7.2: Excerpt of the transcript of the discussion held by the experimental group with an ‘incompetent’ champion**

This exchange summarised in Figure 7.2 was then followed by a shared sense of lack of direction in a relatively tense, uncomfortable environment. Throughout the exchange, the champion remained silent instead of seizing the opportunity to elucidate the group participants as to how the front-end strategizing problem could be framed from an options logic perspective. The group felt left to its own to search for a way to progress the discussion, a situation not dissimilar from those experienced by the control groups. The quality of the conversation that followed was poor, keeping a narrow focus on controversial funding issues that impaired a more rounded conversation about the need for the option and a creative discussion around funding possibilities. At some point, for example, the project engineer engaged in a finger pointing exercise that was not helpful at all: *Money for what? And how much? Why should he [station operator] pay for that landmark building? I don't understand why he should pay. You [regeneration agency] should pay!*" The discussion that followed from that point onwards was overall very inefficient as one participant described: "*it took us quite a long time just to understand what each party wanted and then to start eliminating the possibilities*". Moreover, the group failed to use options logic albeit the presence of the champion.

Interestingly, this 'inefficient' group still managed to produce an outcome that endorsed a built-in option for a landmark building ('*it [landmark building] will not only enhance the station and make it more visible but also aid Salford in getting new investments and developing the area'*). It also addressed the funding issue ('*funding for the landmark building, if not provided by NSIP, will be made bestowed by Central Salford URC*'). One can speculate whether the same outcome would have been accomplished, and the debate on funding the landmark station ignited at all, had the 'incompetent' champion not intervened irrespectively of how incomplete that intervention was. However, this was the only significant intervention of the champion who hardly tried to structure the debate with the design for evolvability methodology that he had been equipped with. As a result, the group discussion was beset by misunderstandings, uncooperative behaviour, and tense exchanges throughout the 2-hour meeting. By the end of the meeting, the group was visibly exhausted and distressed by the fraught nature of the experience. Figure 7.3 includes an excerpt of the transcript that illustrates how the group was still trying to pin down a design concept and funding strategy near the end of the meeting – a situation that was frequently observed with the control groups.

**University:** ok, we agreed on the requirements of alternative d. So, let's see if we can get the funding for £7.5m?
**NR project manager:** when did we agree on alternative d?
**University:** come on, you're just the project manager, you have no stakes.
**NR project manager:** it's our tracks. It's network rail's tracks.
**DfE champion:** how can you say she has no stakes? You cannot say that!
**University:** ok, so what's the problem with alternative d for you?
**NR project manager:** well, in general we would love to have bigger capacity because it seems capacity will increase. In general I think the university would agree with that. So having a bigger station is better since its open to more options.
**University:** and alternative d?
**NR project manager:** alternative d doesn't provide a third platform.
**University:** yeah but alternative d builds the provision.
**NR project manager:** yeah, it might be built in 20 years time, but we don't have it now.
**University:** it says you will be fine up till 2025, which gives you 30 years of bigger capacity. And look at its low cost.
**NR project engineer:** so whoever is against alternative d, please speak now or remain silent forever.
**NR project manager:** alternative d has less capacity. There is a possibility that in 10 years time we have to redo the whole thing again.
**University:** but that's in 13 years.
**NR project manager:** but 13 years is nothing. I mean, we need 3/4 years to get the station done.
**Private operator:** why having such a big capacity at this point when you don't even have the passengers for that?

**Comment [GB1]:** Tries to wrap up the debate and nail down a design concept
**Comment [GB2]:** Tries to find corresponding funding
**Comment [GB3]:** Tense exchanges
**Comment [GB4]:** Tries to investigate potential disadvantages of this alternative
**Comment [GB5]:** Articulates potential advantages of this alternative
**Comment [GB6]:** Visibly tired of inconclusive debate
**Comment [GB7]:** Does not recognize the importance of future needs
**Comment [GB8]:** Puts timescales in perspective

**Figure 7.3: Excerpt of the transcript of the discussion held by the experimental group with the 'incompetent' champion**

The participation of the champion remained subdued throughout the whole meeting. Right at the end, the group was still struggling to reach an agreement. The discussion also started to diverge into other matters. The group started to speculate how to fund changes during project delivery without discussing first what exact changes they were talking about. They then moved to discuss funding of changes during operations, but again without qualifying what those changes might be. The debate had become almost a rudderless conversation (Figure 7.4).

**NR project manager:** OK, so we stick to (d), the council is fine as it seems the third platform is unrealistic for now given the extra costs.
**NR commercial sponsor:** we haven't decided who will pay for any design changes in the future.
**DfE champion:** yeah!
**NR project manager:** that's very true.
**DfE champion:** who's gonna pay for the extra costs?
**NR project engineer:** I think we cannot discuss that.
**Private operator:** depends on the problem that will arise.
**NR project engineer:** are you taking about future uncertainties?
**NR commercial sponsor:** if you freeze the design, right? Then what if at certain point in the future there are changes in the design? For example, we've a certain requirement from the operator saying that we need this or that.
**Private operator:** I don't know what requirement I might have. As I am the operator I might contribute 30/40% of the cost.
**NR commercial sponsor:** What about the other 60%?
**NR project engineer:** we cannot discuss any future costs; we cannot agree on something that we don't know.
**NR project manager:** but I guess in real life we also don't know.
(...)
**University:** if there's a change that requires something that's only going to benefit them [Private operator], then they will pay for it, but that's common sense.
**Private operator:** and what happens if something is benefiting 2 or 3 parties?
**Regeneration agency:** well the percentages will be discussed between the parties when the time comes
**NR project manager:** The landmark building is your [regeneration] responsibility so you should pay for it.
**NR commercial sponsor:** did we discuss about the HLOS?
**NR project anager:** yes
[meeting ends as they run out time]

**Comment [GB1]:** It seems an agreement has been reached.

**Comment [GB2]:** Introduces new conversation about project delivery changes

**Comment [GB3]:** Not helpful remark

**Comment [GB4]:** Reluctant to discuss about it as they do not know what exactly they are discussing

**Comment [GB5]:** Shifts from unqualified changes during project delivery to unqualified changes after the project

**Comment [GB6]:** Finally, they make sense of what they are discussing, even if not related to front end strategizing

**Comment [GB7]:** Participants avoid dealing with the problem due to the lack of information

**Comment [GB8]:** Go back to the beginning of the process , asking the same questions

**Figure 7.4: Excerpt of the transcript of the discussion held by the experimental group with the 'incompetent' champion**

All in all, the front-end strategizing process in this experiment with an 'incompetent' champion unfolded in the same unstructured and unproductive way as systematically observed for the control groups. In agreement to the empirical findings in exploratory field studies, I observed that in the control groups (and in the experimental group with the 'incompetent' champion), the participants were keen to discuss how they wished the design to be, but would invariably struggle to articulate how much their 'dream' design would cost, and how they could collective pay for it. It was also easy for these debates to unravel into multiple random discussions about different issues. The discussions lacked cohesion, and were often fed by speculative and random interventions where different participants were likely to differ in their understanding about what the issue was that they were discussing, as Figure 7.4 illustrates. As a result, the control groups systematically felt genuinely overwhelmed by the nature of the exercise, and found hard to debate future requirements. Figure 7.5 shows an excerpt of the transcript from an unaided group meeting that unsurprisingly struggled to design for evolvability.

**Private operator:** My question is what are we gonna do [to cope with increased demand] after 2025?
**NR project manager:** Are you really concerned with after 2025?

**Comment [GB1]:** Participant ignores the problem as it will not have an immediate impact

**Figure 7.5: Excerpt of the transcript of the discussion held by a control group**

Interestingly, the observation of the experimental group that included the 'incompetent' champion showed that the group still managed to have informal options logic discussions. This is also true for the control groups, a finding that corroborates insights from the field studies. For instance, one project manager could intuitively grasp the optionality around the idea of safeguarding for a 3rd platform (*'the platform might be built in 20 years time, but we don't need to have it now.'*). Likewise, this sense of optionality was understood intuitively by a private operator ('*having such a big capacity at this point would be a waste of money when you don't even have the passengers for that.... let's have another meeting, when we decide to build a third platform in the future').* However, the control groups and the experimental group with an 'incompetent' champion were overall very inefficient in their front-end strategizing process. This inefficiency detrimentally impacted their outcomes – the topic discussed next.

### Insights on effectiveness

The analysis of the simulation results suggests that the experimental groups systematically produced more effective outcomes than the control groups. Interestingly, the majority of the groups ultimately recommended a similar strategy from a concept design perspective. Table 7.5 and Table 7.6 show that 13 out of 17 groups selected alternative d. However, the quality of the experimental groups' recommendations was systematically superior. The strategic recommendations submitted by the experimental groups would be systematically shored up by a documented debate on who would most benefit from building in particular options in the design definition, who should pay for building in these options, and which actors had the wherewithal to provide the additional funding. The findings show the control groups would end up agreeing on a design concept not dissimilar to those proposed by the experimental groups (typically settling for alternative d), but they would inadequately resolve the funding problem, sometimes merely glossing over it. Evidence also suggests that the experimental groups did not shy away from borrowing the constructs of formal options logic to frame the argument, which was crucial to improve the clarity of the outcomes. As one participant of an experimental group recalled:

> "It became clear that given the immediate requirements and the need to hedge against future uncertainties, we were only prepared to seriously consider alternatives that satisfied both. Those that safeguarded the infrastructure now to enable future expansion of a third platform were given the greatest consideration"

**Table 7.5: Summary of the characteristics of the front-end strategizing outcomes for the experimental groups: evaluation and selected quotations**

| Group | Main characteristics of the recommendation | Optionality built in the recommended design | Strategy to fund the options | Documented rationale |
|---|---|---|---|---|
| G1(*) | Alternative (d): De-clutter platform; extend island platform; move access to southern end | Build provisions to build third platform and to include landmark building in the future | Additional £600k for the landmark building will be negotiated with NSIP. If not successful, it will be made bestowed by Central Salford URC | *"I initially wanted the selection of option (f) over option (d) because an additional expenditure of £2.8m would future-proof the design until 2045. However, the project engineer raised the point about the indirect cost of £20m for the third platform, which came as a surprise to all of us"* [NR commercial sponsor] |
| G2 | Alternative (d): De-clutter platform; extend platform; move access to southern end, and develop landmark building | Build landmark building and provisions to build third platform | Contributions for funding the options coming from the central government (NSIP), NR, the Council, the University and private operator | *A staged contribution from the university, based on an increase in its student population...a commitment from the private operator to contribute a percentage of its increased revenue driven by increased footfall* [strategic recommendation] |
| G3 | Alternative (d): De-clutter platform; extend platform; move access to southern end | Build provisions to build new platforms in the future | The group argued that the provisions could be built in, whilst keeping the project within the NISP funding envelope | *Making a decision [to build 3rd platform] now is quite difficult, because we don't know what to expect due to rise in tuition fees, so only in the coming years we will be able to see that.*[strategic recommendation] |
| G4 | Alternative (f) if extra funding for building 3rd platform becomes available; Alternative (d) otherwise | Build provisions to build new platforms in future if funding to build the 3rd platform fails to materialise | Project must be kept within NISP funding. However, it should continue to explore additional funding for building 3rd platform | *To fund (f), we recommended finding a developer interested in investing in a commercial centre in the new station so they could provide equity... The university could provide us the land with free leasing and support funding by imposing an extra charge on tuition fees to students... the city could introduce an extra charge* [strategic recommendation] |

| | | | | |
|---|---|---|---|---|
| G5 | Alternative (d): De-clutter platform; extend island platform; move access to southern end | Stage option<br>Build provisions to build landmark building in 2014; and 3rd platform after 2025 | Keep it within NISP funding but search for funds to build landmark after project completion | *"We'd get in touch with GMPTE and NISP to check whether they have the funding available [for landmark building]. NSIP only funds work on existing platform but GMPTE said they can invest in regeneration works... we don't have £20M for a 3rd platform now and we're unsure if growth in demand will continue, so we'll come back to that in 2020"* [de-briefing session] |
| G6 | Alternative (f) with the option to downscale to option (d) | Build provisions to: (1) build landmark building and (2) build 3rd platform. | Keep it within NR's CP4. Additional contributions from regeneration agency (£2M) and university (£0.2M). | Group postponed the implementation of the 3rd platform to allow assumptions of funding availability to be checked: *Option to delay building a 3rd platform was introduced by URC* [minutes of the meeting] |
| G7 | Alternative (d): de-clutter platform, build a new ticket office, build a new walkway, make it DDA compliant | Build provisions to: (1) build landmark building, (2) add a 3rd platform; (3) extend platform, and (4) add a longer canopy | Group left ill-resolved funding issues, noting funding would be expected from Network Rail and the University of Salford | *The assumption [*£250, 000 for the foundation to be laid for the landmark building] *will be checked in the planning stages. If the assumption is wrong and there are costs involved with incorporating these options into the design, the stakeholders will have to decide whether they want the options or not. If they do, they will have to find funding.*[strategic recommendation] |
| G8 | Alternative (d): De-clutter platform; extend platform; move access to southern end, and develop landmark building | Build provisions to build new platform in the future | University resolved to fund landmark building; NISP funding envelope would cover the provision for 3rd platform | *The University decided to support the construction of a new landmark station building with £0.2M because it is a priority to get a landmark building* [strategic recommendation] |

(*) The champion in this group hardly intervened.

**Table 7.6: Summary of the characteristics of the front-end strategizing outcomes for the control groups: evaluation and selected quotations**

| Group | Main design characteristics of the recommendation | Optionality built in the recommended design | Strategy to fund the options | Documented rationale |
|---|---|---|---|---|
| G9 | Alternative (d): De-clutter platform; extend island platform; move access to southern end | Unresolved | Unresolved | *The huge incremental of funding and operational costs incurred by alternative (f) poses a barrier to the project despite its extra benefits in future-proofing the station up to 2045 [strategic recommendation]* |
| G10 | Alternative (d): De-clutter platform; extend island platform; move access to southern end | Unresolved | Unresolved | *"If I [private operator] put this money can I get it back?" [de-briefing session]* |

| | | | | |
|---|---|---|---|---|
| G11 | Alternative (d): De-clutter platform; extend island platform; move access to southern end | Unresolved | Unresolved | *"So that [alternative e] is inconvenient and it doesn't make the station comfortable for the passengers so if we are doing something, we should think how people will use this platform in the future" [de-briefing session]* |
| G12 | Alternative (d): De-clutter platform; extend island platform; move access to southern end | Unresolved | Unresolved | *"There are a lot of uncertainties. What if the prediction of £7.5M increases until uncontrollable levels? What if student demand is not as expected?" [de-briefing session]* |
| G13 | Unclear | Unresolved | Unresolved | *"We ended up with 4 against 2. With regards to the third platform, four parties were against it from the start and didn't matter what we said to argue for it. There was no way we could persuade them" [de-briefing session]* |
| G14 | Alternative (d): De-clutter platform; extend platform; move access to southern end | Build provisions to build third platform and to include landmark | Unresolved<br>Private operator explicitly rejected any contribution | *"I'm ok with the landmark building, as long as it doesn't come out of my pocket. I don't see any point in me investing money" [de-briefing session]* |
| G15 | Perhaps (f) ambiguous | Not specified | Funding strategy to build a 3rd platform resolved on the assumption Council will pay for it, which is unreasonable to assume according to the case data | *"We couldn't commit, but Northern Rail and the University could see the potential [to add 3rd platform]...there are public and private opportunities, it's a big opportunity for alternative (f) The city also has the potential to grow so they [Council] can contribute" [de-briefing session]* |
| G16 | Alternative (d): De-clutter platform; extend platform; move access to southern end, and develop landmark building | Safeguard option to build 3rd platform in future | Assumes safeguarding of the 3rd platform can be achieved within the NSIP funding envelope; Private operator refused any additional contribution; Unclear about who funds the immediate development of landmark building. | *"The university is expanding, so there's a need to increase the platform length in the future (…) considering the third platform created the most heated discussions among the group" [de-briefing session]* |
| G17 | Alternative (d): De-clutter platform; extend platform; move access to southern end, and develop landmark building | Safeguard option to build 3rd platform in future | University will provide funding for the immediate development of landmark building; Group does not resolve who will fund the safeguarding provision for the 3rd platform | *Alternative D leaves room to address future capacity issues* [strategic recommendation] |

Interestingly, the recommendation developed by one experimental group went further in its comprehensiveness to the point of including a well-thought plan, bought in by all the affected parties, to fund the cost to design in the options. In this case, the design for evolvability framing was exceptionally successful in bringing to the foreground the difficult conversation on how to fund the design provisions needed to build in the desirable options. The conversation successfully revealed the forces in tension, and spurred the team to think creatively and hammer out a funding plan. One participant said:

> "Once we agreed upon the project design, it came down to a matter of sourcing funds from the stakeholders. We all understood the urgency of the situation and the need to arrive at a decision. This resulted in some creative negotiations that involved the promise of future commitments in the form of a percentage of future revenues"

The experimental groups also produced strategic recommendations that demonstrated they scrutinised the potential options in terms of pros and cons, costs, implementation dates, and sponsorship. For instance, the strategic recommendation of one experimental group provides evidence of how the formal assessment of different scenarios contributed to the quality of the outcome. The group included in the documentation that submitted a comparison of three different scenarios for building a landmark building (Table 7.7). The first was a baseline scenario where the landmark building is not built and no option is built-in. The second scenario does not build the landmark building, but safeguards the land for potential future development. Finally, the third scenario safeguards the land and proposes to build more robust foundations to enable the economic adaptation of the building in the future. By assessing the pros and cons of each scenario, the group became aware of the implications of preparing the foundations for the future landmark building. They knew they would need additional funding, and that triggered the negotiation for the option sponsorship:

> "The University has agreed to put down £200,000 and the Network Rail commercial sponsor £50,000 to 'reserve' the land and build a foundation for a landmark building. The NR commercial sponsor has also committed to partly fund the building in the future" [minutes of the meeting – G7 experimental group]

**Table 7.7: Comparison of different alternatives produced by one experimental group (G7)**

| **Option A** | **Build a landmark station building** | | |
|---|---|---|---|
| **Alternative concepts** | **Baseline scenario:**<br><br>**No option built-in** | **Alternative 1:**<br><br>**Option partially built-in** | **Alternative 2:**<br><br>**Option fully built-in** |
| Brief description | Nothing is done on the land. | Reserve the land for a future building | Lay down the structural foundation for the future building |
| Additional capital costs | 0 | 0 | Cost of foundation. Approx. £250,000 |
| Exercise costs | Unfeasible:<br>Costs of finding and clearing land, adapting current designs in addition to building costs | Cost of foundation and cost of building. Approx. £1.2M + £250,000 + costs of adaptation | Cost of building. Approx. £1.2M |

Overall, the clarity of the strategic recommendations was consistently higher for the experimental groups. The experimental groups further scrutinised the funding implications of endorsing a potential option as opposed to simply endorsing the option without bothering to assess the implications. As a consequence, the experimental groups were able to provide comprehensive assessments and engage in grounded conversations around the financial sponsorship for the options. The experimental groups were able to clearly understand which organisations would most benefit from those options and what would be the cost implications of endorsing them. It is no surprise then that these groups were more successful in finding particular stakeholders willing to sponsor a particular option compared to the control groups. Table 7.8 summarizes the data on the effectiveness of the experimental and the control groups.

**Table 7.8: Comparative analysis of performance effectiveness: selected quotations**

| Category | Control Groups | Experimental Groups |
|---|---|---|
| Clarity | Hybrid: Clear design strategy, but inadequate discussion on funding strategy; ambiguity on future actions<br>*"We had no trouble to agree on alternative (d) as our solution, but we didn't discuss how to finance it which was the second most expensive amongst all" [Regeneration agency rep]*<br>*"Alternative (d) can meet the comfortable level until 2025, although we still don't know what we will do in 2025; we're going to talk about it later on" [Regeneration agency rep]* | Consistently high<br>*"We designed for the potential increase in revenue due to footfall and retail. We achieved financial commitment from all parties around the table. [NR commercial sponsor]*<br>*"We wanted to add an option for a third platform and prepare to do this in case capacity would be reached in 2025 as Northern Rail was not prepared to invest now and the rise in tuition fees precluded us to use historical data on student demand" [Champion]* |
| Comprehensiveness | Moderate: vague on funding issues<br>*"The university could consider investing up to £200,000 to the costs of the landmark station building" [strategic recommendation]* | High: trade-offs and assumptions consistently discussed and documented<br>*"Stakeholders were mostly pro a 3rd platform, although we all agreed the current passenger numbers and the uncertainty about growth, and thus its potential benefits didn't justify such a large increase of funding for building it right away" [NR Project manager]*<br>*"It was up to us to make a decision that would be acceptable to all the involved parties, while balancing the critical constraints of time and costs" [Train operator rep]* |
| Buy-in | Low: systematically unresolved conflicts<br>*"It was extremely difficult to reach the final decision because one alternative was cheaper but it would only serve demand up to 2025, and the other alternative was much more expensive but would serve demand up to 2045" [NR project manager]* | Yes: High Goal congruence<br>*"Essentially, our thought process was that we pay now for the option for future expansion so we don't have to come up with the extra funding yet – the foundations would be put in place should they be needed in the future" [Train operator rep]* |

## Analysis on satisfaction

The analysis on satisfaction was based on 101 questionnaires collated throughout the experimental research. Figure 7.6 shows the average and standard deviation of the responses for each statement. The first eight statements relate to the perceived usefulness of the front-end strategizing process. The following seven statements characterize the extent to which respondents are satisfied with the quality of the information in the institutional support that they received. In addition to the design briefs received by the control groups, the experimental groups also received further information on design for evolvability imparted by the champion. The last four statements relate to the quality of the interface between the group members and the information on the front-end strategizing process that they received prior to the exercise. All participants were able to access the information by downloading the design briefs and background information on the parent organisations from a web link that they received in a bespoke email a week prior to the start of the exercise. In the case of the participants in the experimental groups, the role of the champion was also interpreted as an element of the interface between them and the information on the front-end strategizing process. The responses for the two groups varied marginally, and the descriptive statistics did not show any statistical significant difference between the two groups.

| Questionnaire Statements | Control | | Experimental | |
|---|---|---|---|---|
| **System Usefulness** | **Mean** | **StDev** | **Mean** | **StDev** |
| 01 – Overall, I am satisfied with how easy it was to front-end strategize the Salford Crescent project. | 2.846 | 1.136 | 3.533 | 1.460 |
| 02 – It was simple to do the project front-end strategizing. | 3.400 | 1.392 | 3.566 | 1.482 |
| 03 – I could effectively complete the project front-end strategizing. | 2.925 | 1.289 | 3.172 | 1.546 |
| 04 - I was able to complete the tasks and scenarios quickly. | 3.375 | 1.462 | 3.746 | 1.593 |
| 05 - I was able to efficiently complete the tasks and scenarios. | 3.025 | 1.250 | 3.336 | 1.344 |
| 06 - I felt comfortable with the project front-end strategizing process. | 2.850 | 1.562 | 2.615 | 1.219 |
| 07 - It was easy to learn how to project front-end strategize. | 3.225 | 1.577 | 2.992 | 1.192 |
| 08 - I believe I could NOT become more productive in project front-end strategizing. | 4.513 | 1.760 | 5.050 | 1.712 |
| Average 1 through 8 | 3.270 | 1.514 | 3.501 | 1.592 |
| **Information Quality** | **Mean** | **StDev** | **Mean** | **StDev** |
| 09 – The information received as part of the institutional support clearly helped us to fix problems. | 2.700 | 1.363 | 3.402 | 1.620 |
| 10 - Whenever there were disagreements among participants, the information received as part of the institutional support helped to overcome them easily and quickly. | 2.821 | 1.144 | 3.631 | 1.420 |
| 11 – The information received as part of the institutional support was adequate. | 2.650 | 1.477 | 3.320 | 1.602 |
| 12 – It was easy to leverage the information received as part of the institutional support. | 2.975 | 1.423 | 3.205 | 1.459 |
| 13 - The information received as part of the institutional support was easy to understand | 2.900 | 1.277 | 2.443 | 1.323 |
| 14 - The information received as part of the institutional support was effective in helping us complete the tasks and scenarios. | 2.846 | 1.204 | 2.943 | 1.449 |
| 15 - The institutional support was well structured. | 2.575 | 1.483 | 2.583 | 1.331 |
| Average 9 through 15 | 2.781 | 1.338 | 3.075 | 1.507 |
| **Interface Quality** | **Mean** | **StDev** | **Mean** | **StDev** |
| 16 - The institutional support was easy to access. | 2.475 | 1.536 | 2.258 | 1.091 |
| 17 - I liked undertaking this project front-end strategizing with the level of institutional support that was provided. | 2.875 | 1.771 | 2.525 | 1.376 |
| 18 – The institutional support provided had all the qualities that I expect it to have. | 2.875 | 1.539 | 3.075 | 1.402 |
| 19 - Overall, I am satisfied with the institutional support that was provided. | 2.775 | 1.687 | 2.642 | 1.429 |
| Average 16 through 19 | 2.750 | 1.629 | 2.625 | 1.356 |
| **Overall Satisfaction (average 1 through 19)** | **2.980** | **1.331** | **3.160** | **1.549** |

**Figure 7.6: Descriptive statistics of the responses to the questionnaire on satisfaction**

A comparative analysis of the descriptive statistics based on the questionnaires suggests no statistically significant difference in the level of satisfaction of both groups with the front-end strategizing process. This result is based on a two-sample T-test (assuming unequal variance). The null hypothesis stated that there were no statistical differences between the mean satisfaction of the two groups ($H_0$: $\mu_1=\mu_2$). The alternative hypothesis stated there were differences ($H_0$: $\mu_1 \neq \mu_2$). I also conducted a T-test to compare system usefulness, information quality, and quality of the interface. Likewise, the null hypothesis stated that there were no statistically significant differences between the variables, whereas the alternative hypothesis stated there were differences. These hypotheses were tested by first calculating the mean and variance of each variable. The p-value for the two-tailed test was then computed, i.e., the probability that the test statistically equals the observed value or a value even more extreme in the direction predicted by the research hypothesis (Agresti & Finlay, 1997). $H_0$ was rejected if the p-value was lower or equal to the specified level of significance for the analysis (assumed at $\alpha=0.05$). The differences between the assessments of the two groups are not statistically significant in the intensity of the positive assessment. The p-values for the overall satisfaction and for the three dependent variables are higher than the specified level of significance (summarised in Table 7.9). Therefore, $H_0$ cannot be rejected and it is not possible to say that there were statistically significant differences between the two groups.

**Table 7.9: Descriptive statistics of Assessment of Satisfaction and T-test two-sample assuming unequal variance (7-point Likert scale; 1=strongly agree, 7=strongly disagree)**

| | System usefulness | | Information quality | | Interface quality | | Overall Satisfaction | |
|---|---|---|---|---|---|---|---|---|
| | Control group | Experimental group | Control group | Experimental group | Control group | Experimental group | Control group | Experimental group |
| Mean | 3.267 | 3.499 | 2.781 | 3.080 | 2.750 | 2.647 | 2.978 | 3.164 |
| Variance | 0.979 | 0.962 | 1.257 | 1.275 | 2.144 | 1.330 | 1.031 | 0.729 |
| P(T<=t) two-tail | 0.251 | | 0.194 | | 0.710 | | 0.341 | |

This result is not interpreted as bad news. Hypothetically, the experimental groups could have perceived that the design for evolvability proposition was introducing an obstructive, time-consuming, and bureaucratic procedure that added more rules and slowed down decision-making. Put differently, the design for evolvability could be interpreted as adding red tape to the front-end strategizing process. The statistical analysis of the experimental findings disconfirms this conjecture. One participant in an experimental group described the front-end strategizing process as an 'enjoyable and useful experience'. Another participant also noted that: "having him [champion] was important to help channel an outcome and draw out the most from the stakeholders". Participants in the experimental groups could also dislike the loss of freedom to do things their own way. That was not the case either. The findings suggest that the experimental groups managed invariably to use the design for evolvability framing as a support tool to the design decision-making process, rather than a tool that limited their ability to make design decisions. Some experimental groups even created an agenda for the meeting that followed almost step by step the design for evolvability framing (appendix G shows an example).

Interestingly, the control groups were equally overall satisfied with the front-end strategizing process, but they felt systematically overwhelmed by the amount of conflicting interests and priorities that needed to be reconciled. As one participant said: *'the list [of conflicting goals] became exhaustive after we carefully recorded every opinion because they diverged to a great extent, which made the process too complicated and overloaded'*. This particular group ended up running out of time as documented in the meeting minute:

> "Due to the short time nature of this exercise, we had to express our goals and concerns sometimes very explicitly to be clearly understood… Still, we didn't discuss how to finance our recommendation, which was the second most expensive."

A similar situation occurred with another control group. One participant of this group pointed out the frustration with failing to bridge the divergent interests during a debriefing session in the class:

> "We ended up having four [stakeholders] against two. With regards to the third platform, the other parties were already against it from the start. It wouldn't gonna matter what we said in order to argue for it. There was no way we would persuade them."

Interestingly, some participants in the control groups even demonstrated interest in having a more structured approach to support the front-end strategizing process. As one noted: “it would be useful to have a structured output sheet for summarizing it more clearly”. Table 7.10 summarises the qualitative data on the satisfaction of the two groups. The contribution of the empirical and experimental findings to the theory and practice is discussed in the next chapter.

**Table 7.10: Comparison between the overall satisfaction of the two groups: evaluation and selected quotations**

| Category | Control Groups | Experimental Groups |
|---|---|---|
| Overall Satisfaction | Positive, but teams typically overwhelmed by conflicting interests<br><br>*“The discussion was productive and detailed while we’re working under the same goal...but it was particularly hard because of a great number of different opinions and perspectives”* [Train operator rep]<br><br>*“Each one had different demands, different requirements, and different expectations about the project. So sometimes we needed to modify our expectations to cover the expectation of other people, and the other people need to modify a little bit theirs… Finally we chose this one [option d]. I think it’s better for everyone, but mainly we are in a situation that not all the people will be happy at the end”* [Train operator rep] | Positive<br><br>*“A great opportunity...I found the exercise very interesting” [University rep]*<br><br>*“The champion was able to advance the discussions and encouraged the participants to take decisions”* [Regeneration agency rep]<br><br>*“After taking part in the exercise, I can definitely say that the design for evolvability framing was helpful to improve the process” [Champion]* |

# 8 Final Considerations: Research Implications and Outlook

## 8.1 Summary

The project-based design and development of new physical infrastructures requires dedicating careful attention to understand how the functional and operational requirements may evolve during project delivery and over the operating lifetime. This visioning exercise at the front-end is necessary to make early design decisions on how to ensure that new infrastructure assets can economically adapt to foreseeable changes in the future. To design an asset to cope economically with these potential changes, project teams need to assess and discuss at the early stages of the project whether building provisions in the design will pay off the additional upfront investment. These provisions come in the form of investments in modularising design architectures or safeguarding integral architectures. Designing an asset to be resilient to foreseeable changes in the environment, however, can require large sums of investments upfront. Additionally, there is no guarantee these investments will pay off, in many ways working similar to buying an insurance policy. In a world where capital resources are increasingly scarce and the costs of capital projects are spiralling, investing in design for evolvability is therefore not trivial. These investments at risk need to be balanced against other investments that may have more guaranteed pay-offs in the short-term.

The early design decision-making process therefore requires negotiating trade-offs and design priorities. These critical decisions are challenging. If the assessments are made too late, commitments that are gradually made as the design progresses are likely to increase significantly the costs of incorporating provisions that will allow adapting the design in the future. This means decisions on design optionality need to be made under conditions of high uncertainty and ambiguity at the project front-end. Additionally, project teams may find it inappropriate to use the analytical real options tools available as they struggle to find reliable information on how the problem can be modelled and on which numeric assumptions they need to make. This dilemma faced by capital project teams at project front-end strategizing is at the heart of this research: how to design and develop new physical infrastructure assets that can adapt and evolve economically to cope with future changes in design requirements?

The literature review showed that the established practices to manage capital projects, and more specifically project risk management, offer inadequate support to help project teams cope with the challenge of making early design decisions under high uncertainty. However, this research fieldwork revealed that the mathematical apparatus provided by real options analytical tools is also inadequate to support mundane design decisions at the project front-end. For example, the findings of the initial exploratory empirical study on the front-end strategizing of a simple viaduct were remarkably in agreement with literature. They showed that project teams informally use options thinking to assess whether provisions in the form of design modularity or safeguarding should be incorporated in the project concept design, despite not being aware of options theory. In other words, the project teams adopted the inside view (Lovallo and Kahneman, 2003) to decide which options should be built in the design of the new viaduct. Unstructured decision-making processes are however vulnerable to cognitive bias and organizational pressure and incur higher probabilities of producing over optimistic assessments. The exploratory study also showed that any attempt to encourage project teams to use complex mathematical formulas requiring a large number of numeric assumptions to assess relatively mundane design decisions would be likely to fail. The embedded case study on NR capital projects also corroborated these empirical findings. The NR case study further showed how the difficulties of making capital optionality decisions on design for evolvability become amplified whenever the project involves multiple funders. Crucially, the NR case study revealed that multi-stakeholder project teams systematically resort to a combination of informal options logic and ‘money talks’ to resolve conflicting priorities and select a concept design at front-end strategizing. The conversations underpinning the optionality decisions at front-end strategizing invariably unfolded under conditions of uncertainty and occasionally sharp asymmetry in stakeholders’ capabilities, wherewithal, and political power to influence design decisions. Tensions invariably surfaced whenever stakeholders demanding a capital investment, in particular provisions to ensure the asset can cope economically with foreseeable future changes, lacked the wherewithal to commit any capital investment. The issues observed in the fieldwork pointed to an opportunity to formalise a design for evolvability framing.

The final stage of the research consisted of conceptualizing a proof-of-principle of a formal framing to design for evolvability and setting up a two-group controlled experiment to validate its usability. The conceptualization of the proof-of-principle of a novel framing was based on the cross-fertilization of the literature on project risk management and real options with insights from the fieldwork. The validation involved a lab-based experiment that simulated the front-end strategizing process for the Salford Crescent Redevelopment project, a £12M project that involved a relatively large number of stakeholders. For the experiment, this study assembled two distinct types of groups of graduate-standing students. Some groups received the help of a design for evolvability champion and were asked to follow a structured design for evolvability process. The other groups did not receive any additional support. The results of several runs of the experiment were analysed statistically in order to compare the performance of the two types of groups in terms of effectiveness, efficiency, and satisfaction. The analysis of the results obtained from organising 17 experiments involving 107 participants were in agreement with the empirical findings. They suggested that a formal design for evolvability framing can improve the overall performance of front-end strategizing capital infrastructure projects without getting push back from the project teams or demanding huge coordination efforts. The results also showed that the effectiveness of a formal design for evolvability framing is dependent on the technical competence of the design for evolvability champion. This role was purposefully created to test the usability of introducing a formal design for evolvability framing at project front-end strategizing. The analysis of the experiment findings showed as discussed next that unless the people in charge of implementing a design for evolvability procedure perform their role competently, the effects of introducing a formal framing will be negligible.

## 8.2 Contributions to Theory and Practice

This research offers contributions both to theory and practice. In the theoretical front, one of the major contributions is the introduction of a new framing for capital project front-end strategizing that pivots around the notion of design for evolvability. Conceptually, this framing builds on research on real options reasoning and flexibility, and explores the applicability of extant research to support mundane design decisions in capital settings. This framing also adds to research on the proactive management of project risks by proposing a role – the champion of design for evolvability – and a structured way to resolve the front-end in a multi-stakeholder environment that can complement established risk management practices. The novelty of the design for evolvability framing is associated with the proposition that a formal structure is needed to improve the quality of the conversations during the front-end strategizing process. The experiment shows that a design for evolvability framing not only facilitates and accelerates the decision-making process at the front-end, but also ensures that discussions on design optionality and funding which are integral to this process are not brushed aside or procrastinated simply because they are not easy.

Whilst DfE has not been purposely designed to force decision-makers to play their design decisions against the quality of analogous decisions made in the past and control for cognitive biases, it is fair to say that DfE likewise encourages teams to take an outside view (Lovallo & Kahneman, 2003). Specifically, DfE forces decision-makers to make explicit their assumptions about future states of the world, interrogate whether what they can and cannot foresee ahead justifies upfront investments in design flexibility, assess whether those investments are affordable, and ultimately agree multilaterally on a plan for what to do next.

By ensuring the difficult conversations take place, a structured and more efficient front-end strategizing process has the potential to also become more effective. The analysis of the experiments is telling. It shows that the groups aided by the champion (apart from one exception) systematically developed better strategic recommendations, which were shored up by documented debates on who would most benefit from particular options, who should pay for the option costs, and which actors had the wherewithal to provide the additional funding. Conversely, the groups that did not follow a design for evolvability structure more often than not lacked time to debate funding strategies, and were less creative in putting forward ways to resolve the problems.

Admittedly, many procedures exist to guide decision-makers on managing project risks. The PMBOK®, for instance, provides project managers with recommendations on how to identify, analyse and respond to project risks (PMI, 2004). This and other similar processes, however, fail to exploit the power of built-in optionality in design as a means to mitigate foreseeable risks. Established risk management practices also fail to adequately provide multi-stakeholder project teams with mechanisms that can help the stakeholders reconcile their different views of the world and coalesce their perspectives into a project strategy at the early stages. Rather, established risk management practices for capital projects tend to be geared towards controlling execution to avoid deviating from goals set ex-ante as if the project could proceed insulated from changes in the environment (Lenfle & Loch, 2010) – section 2.1.2 offered a full discussion. This prescriptive approach relying on control and contingent planning is in marked contrast with more experimental approaches common in product development project environments. These approaches accept that project front-end strategizing happens under conditions of uncertainty, and encourage teams to undertake iterative searches and even invest in the development of multiple alternatives in parallel until more information becomes available (Thomke & Fujimoto, 2000).

Of course, the prototyping nature of capital projects, and the typical overlap between construction of the first physical systems with design for the last systems to be installed (e.g. fit out), limits the flexibility in the process to accommodate iteration and investment in multiple design alternatives. Nevertheless, the results here show there is some flexibility in capital projects to leave options open at front-end strategizing. This requires that multi-stakeholders teams think in terms of design for evolvability. The stakeholders need to discuss and agree at the project front-end what flexibilities they want to design in the product definition, who should pay for flexibility, when and why the flexibility should be designed in, and how much the built-in flexibility costs. These are difficult conversations, and this research results suggest there is value in creating an institutional role as a coordination mechanism (Bechky, 2012) – the design for evolvability champion – and empower the champion to encourage stakeholders to structure the multilateral conversations and collectively seek answers to those questions at the early stages of the project. Admittedly, in some situations, stakeholders might lack enough information to answer all those questions as the empirical findings illustrate. Nevertheless, the explicit discussion guided by an empowered champion will help stakeholders become aware of the potential costs, value and risks associated with early decisions to build design flexibility. Furthermore, a design for evolvability framing will ensure that stakeholders face the opportunity to incorporate flexibility in the conceptual design when flexibility is less expensive to design. It will also ensure that stakeholders discuss the implications of not endorsing investments in design flexibility and accept accountability for the decisions irrespectively if they endorse flexibility or not.

This research also adds to real options theory. First, the exploratory case study (Chapter 4) has corroborated the claims that project teams use options thinking intuitively (Busby & Pitts, 1997; Gil, 2007; Hult et al., 2010; Nagali et al., 2008), but that the analytical tools available from the real options apparatus would be inadequate to support relatively mundane optionality decisions at the project front-end (Bowman & Moskowitz, 2001; Lander & Pinches, 1998). Subsequently, the embedded case study at NR uncovered the multi-stakeholder nature of optionality decisions and the intertwinement between design optionality decisions with funding issues. This is an important finding as advocators of real options theory gloss over the actual cost of the options. They may do so understandably because in macro investment situations, the optionality costs tend to be marginal relatively to the value of the options they can create. This is not the case however when applying real options reasoning to more mundane design decisions. In capital projects unfolding in a context of scarce resources, decisions to invest in optionality use capital resources that could otherwise be invested elsewhere. This means optionality decisions are intertwined with a debate around, first, whether the options are really necessarily, and second, if they are, who ought to pay for the costs of the option, especially if those costs are not marginal relatively to the value that the option can add to the project definition.

The difficulties to untangle investment in design optionality from sources of funding as illustrated by the embedded case study on NR front-end practices show that it would be unrealistic and unfeasible to adopt real options mathematical tools when multiple stakeholders are involved. Representing such decision-making environments that involve investments in multiple interdependent options with mathematical models would be overwhelming and would require expensive specialised resources unlikely to be available to support capital project teams. For the sake of tractability, the mathematical models would also need to be oversimplified which would create issues about the extent they represent real-world scenarios at all. Also, differences in perceptions across stakeholders would make it very difficult to agree on numeric assumptions. For that reason, this research developed (chapter 6) and validated (Chapter 7) a new framing which is based on qualitative real options reasoning (McGrath & MacMillan, 2000; Mcgrath & Nerkar, 2004). The new framing allowed to operationalize the systematic use of options thinking in a complex stakeholder environment. The experiments show that a systematic use of real options reasoning in the early design decision-making allows capital project teams to assess and discuss design optionality and its costs and benefits more efficiently, and as consequence, make more effective strategic decisions.

This research also contributed to bridge the gap between two research streams that have remained largely separated: risk management and real options. The new framing was developed by intersecting these two literatures, responding to calls for integrating risk management with options thinking (Miller & Lessard, 2007). Admittedly, this is not the first study exploring this intersection. However, prior work combining the two literatures has mainly focused on holistic optionality decisions, e.g. to endorse or not the overall capital investment (Neufville et al., 2008; Trigeorgis & Smit, 2009). This research is innovative in the sense that it analyses how to combine risk management and options thinking when project teams need to make more mundane design decisions in a project that has already been endorsed at a higher level. This is a fundamentally different problem. In major investment decisions, the cost of the option is often marginal relatively to the potential payoffs and the final decision may be the full responsibility of one party (Neufville & Scholtes, 2011). This is not the case in mundane design decisions. Decisions to endorse some options require trade-offs if capital resources are scarce. Some of the optionality costs may not be marginal relatively to the potential benefits especially in the case of investments to actively safeguard integral design architectures. Moreover, decisions to invest often need to be negotiated with two or more parties. Hence, this research provides project teams with theory and a proof-of-principle of a method that can successfully support the decision-making on flexibility when (1) there may exist a relatively small asymmetry between the costs and the benefits of the options, at least as perceived by some stakeholders; and (2) when project teams face urgency to make design decisions and lack capital resources to employ experts in options analysis. The contribution relies less on the quantitative aspect of the management of risk, focusing instead on the qualitative aspect of the management of risk. As a result, the new framing does not offer precise numerical strategic recommendation to optionality investments. Instead its value lies in offering a structured process through which the project team can collectively assess the costs, risks, and potential benefits of different optionality investments and make a judgement call over which investments it should endorse in a context of scarce resources and of awareness for risks of premature obsolescence of the asset.

From a methodological perspective, this research contributed to calls for undertaking more experimental research in order to complement observational (empirical) research and pure theoretical studies (Croson et al., 2007). It also adds to recent work exploring how training on flexibility can improve project front-end strategizing. Recent experimental work in this area finds that an investment in early educating design decision-makers on fundamental concepts in options logic impacts positively project performance (Cardin et al., 2012). This doctoral research shows however that reality is more complex as seldom early design optionality decisions are undertaken by one individual. Instead these decisions hinge on multilateral debates that can be especially challenging when multiple stakeholders present different financial capabilities, knowledge bases and conflicting interests. Crucially, the two-group controlled experiments confirmed the initial hypothesis that the formalization of optionality thinking through a design for evolvability framing can improve the overall performance of the front-end strategizing process. By controlling the sources of variation and ensuring that both groups (control and experimental) differ only in terms of the presence of a design for evolvability champion, the independent variable, the experimental results established causality in a relatively clean way. This allowed asserting that the variation of the independent variable had caused changes in the dependent variables, all of which related to the overall performance of the front-end strategizing process.

From a practical perspective, the proof-of-principle of design for evolvability sheds light on how practitioners can try to formalize the assessment of design options and incorporate this assessment into risk management practices. This formalization is a first step to help resolve the complicated intertwinement between options logic and 'money talks' at front-end strategizing uncovered by the fieldwork. Importantly, the empirical and experimental findings revealed that project teams are unlikely to push back the idea of adding a layer of formalisation related to future-proofing the design of new infrastructures. It also revealed project teams are unlikely to shy away from efforts to increase the accountability for the early design decisions.

In capital project environments, proposed framings to formalise options logic need to be simple to be accepted by practitioners who have for years balked at efforts to adopt real options theory (Bowman & Moskowitz, 2001; Lander & Pinches, 1998). Decision-makers at the project front-end also often struggle with lack of resources and urgency to make decisions, two factors that can make it hard for them to endorse complicated structures for decision-making. Nevertheless, failure to diligently think through early design alternatives under conditions of uncertainty can have dramatic consequences to project performance (Morris, 2011). This makes a case to continue to search for structures to help improve the quality of front-end strategizing. To entice users, evidence needs to show these structures can make the process more efficient and effective and satisfy the users. It is heartening that the experimental results confirmed that a design for evolvability framing meets these criteria. The results show that the participants of the experimental groups were almost invariably more efficient and as a result capable to produce more comprehensive recommendation strategies. The experimental results also refuted the conjecture that users would perceive any new procedure as obstructive, time-consuming, and bureaucratic. These are important contributions to practice.

### 8.3 Limitations and Future Research Directions

The results of this study suggest several ways to further this research. The experimental methodology lends itself to be developed in a number of ways. The development of a sophisticated method to design for evolvability was not the main goal of this research. The proof-of-principle of a method to design for evolvability is a simplified realization of a new framing for the purposes of undertaking comparative experimental analysis. Further work could explore the implications of adopting a more sophisticated method in the project front-end strategizing. Computer-based methodologies could also be developed to support experimental analysis. One advantage of using computer-based methodologies over the procedure chosen for this research is that the qualitative and quantitative data generated by the participants during front-end strategizing meetings could be recorded in more detail. A complementary study could also investigate the implications of including even more stakeholders at front-end strategizing meetings, and the extent to which the benefits from introducing a formal framing still hold.

Noteworthy, the lab-based experiments involved graduate-standing students. The laboratory conditions for setting up the experiment were critical to standardise the knowledge base of the different teams of students. By creating a level playing field across all the teams of graduate-students, the experiment then allowed to investigate potential causality between adopting a formal design for evolvability framing and changes in performance at front-end strategizing. This was possible by contrasting the performance of teams that were aided against those that did not benefit from the help of a design for evolvability champion. All other conditions were the same, an important factor to ensure the internal validity of the experiment. Further research is however required to increase the external validity of the experiment, i.e., the extent to which the experiment offers an accurate representation of a real-world situation. For example, it would be interesting to undertake the experiment with practitioners from the economic sectors involved at front-end strategizing, railway, local authorities, redevelopment agencies, university. This would allow to investigate whether the impact of introducing a design for evolvability framing changes when professionals are actually doing the task. Action research could also be tried to further explore the benefits of designing for evolvability. This would require developing a more sophisticated proof-of-principle and identifying a real-world capital organization that would agree to test the proof-of-principle in the front-end strategizing meetings for a sample of projects within an universe of similar capital projects. Alternatively, a line of enquire to further external validity can combine both previous suggestions, i.e., conducting experiments involving a more sophisticated design for evolvability methodology and using professionals rather than students to undertake the experiments.

Another line of research that merits further work pertains to the creation of the role of design for evolvability. As often happens in the real world, the role was institutionalised in the experiment (Bechky, 2012) the participants who assumed the role of the champion of design for evolvability received training on the method to design for evolvability before the front-end strategizing meeting. However, individuals were not selected for the role based on their technical competence and personality. Rather, students were allowed to select the roles each one wanted to perform. As a result, the results suggest some errors in casting particularly in regards to those performing the role of champion. By the nature of this role, the champion needs to be outspoken and assertive in order to persuade a team of professionals to adopt a structured process as they front-end strategize the process. In one occasion, however, the observations of the experiment situation revealed that the champion did not perform the role adequately despite the training conditions offered being exactly the same. There was a clear issue of poor fit between the student's personality and the nature of the tasks inherent to performing the role. As a result, the group that received aid failed to outperform the unaided groups. They exhibited instead a level of performance aligned with the unaided groups whose conversations would often resembled a succession of hit or miss trials. The underperformance of this group was largely explained by the individual's lack of competence and poor fit with the role of the champion of design for evolvability. This result amplifies the importance of ensuring that the champion is well trained and fits the role. A procedure cannot improve performance just because organisations adopt it. Performance improvements require that organisations get their implementation right. Otherwise, the adoption of a new procedure can become nothing but a piece of red tape that adds costs without adding value.

Still, this result is an exception. All the other groups that benefited from the help of a champion performed well. The champions ensured people would look at the different alternatives, that they assessed them meticulously before ruling one out, and then engaged in a serious conversation about the sources of funding for optionality. This exception is nonetheless worth discussing. Despite being a straightforward process, the formalisation of design for evolvability is still dependant on the champion's ability to perform the role, i.e., communicate and enforce the steps that the project team needs to follow as they progress through the front-end strategizing process. In the experiment, the training of the champions happened through a workshop that lasted approximately one hour. During this workshop, the champion was educated on the essential concepts and relationships in options thinking, and was encouraged to ask the questions necessary to prompt option thinking and to ensure a complete analysis. The level of empowerment, however, was limited as ultimately all participants were students in the same circumstances. Whether the role would be perceived different if a word like leader had been used instead of champion is also an open research questions. The extent to which the role would gain legitimacy over time as the design for evolvability practice would become more routinized is another open question. Clearly, further investigation is needed to draw more general conclusions as to the extent the training and the personality of the individual impact on the front-end strategizing process.

Conceptually, this question creates opportunity to intersect this work with role theory (Biddle, 1986) to better explore the impacts of creating an institutional role that is likely to shake established practices, and how that role may be interpreted by the surrounding environment. The experimental results suggest that the role was generally effective, which allows to assume that people received adequate institutional support to play the role, and that the role was by and large correctly interpreted by the other group participants. There was one exception where the champion input made a marginal difference due to a problem of misfit with the personality of the student. Nevertheless, it is plausible to assume that in the real world recruitment would manage to pre-empt problems of personality misfit, and people with the right qualities would be assigned the role of champion of design for evolvability. Theory also suggests the legitimacy of the role could be expected to grow over time provided the organisation invested in developing the role in its environment, educating the workforce about its importance, and in giving the role adequate institutional support (Bechky, 2012). For the environment to gain confidence in the role instead of becoming cynical about it, the organisations would need to demonstrate that the role adds value. This means that more research is needed to understand better how this role – the design for evolvability champion – can work in practice.

In the experiments, the champion was endorsed by the project sponsor but was championing an agenda that was neutral in regards to whether the collective ought or not to invest in design flexibility. This begs the question as to whether the experimental results would have been different if the role was endorsed by a different organisation. The experimental results also leave unanswered the question of whether there might be a better organisation in the stakeholder ecosystem to host the role. Moreover, the experimental results only contrast two extreme situations – groups that received champion support against groups that receive no aid. In the real world, however, meetings involving multiple stakeholders often receive support from a professional facilitator. The facilitator is unlikely to have received specialised training in design for evolvability, but plausibly can contribute to build common ground across stakeholders, help to ensure everyone has a voice in the meeting, and attenuate the detrimental effects of idiosyncratic personalities (excessively shy, excessively overconfident) to the quality of the conversation. It remains unclear how much value a champion of design for evolvability adds relatively to a traditional meeting facilitator. These are important research avenues to understand better the costs of recruitment and training that capital organisations should expect to incur if they plan to create a design for evolvability role and want to ensure the champion performs the role competently.

## 8.4 Final Considerations

Taken together, the analysis of the empirical studies and the two-group controlled experiment show that the adoption of a formal design for evolvability framing to support early design decision-making have the potential to improve the quality of the overall performance of front-end strategizing. These findings are important. The literature review shows that the traditional risk management practices hardly address the potential of investing in design flexibility as a means to mitigate risks of costly changes during project delivery and the operating lifecycle. Rather, established risk management practice, with its emphasis on change controls and governance, is primarily geared towards scrutinizing the need to instruct late project stages, and demanding that changes be only allowed to go forward if underpinned by compelling business cases. Practice therefore fails to acknowledge the power of design decisions at project front-end strategizing to proactively create a capital project environment amenable to change. Empirical insights from the embedded case study on Network Rail capital projects showed instances in which limited investment is made at front-end strategizing to assess design flexibility. Rather, project teams may opt to ask for expensive contingency budgets to compensate for the high uncertainty in project requirements. As a consequence, project funders may be reluctant to continue to sponsor the subsequent project stages, and the project bears the risk of being dropped if funders cannot afford them. Alternatively, projects with rigid design architectures may proceed at risk of costly change in the future, when some incremental investments in design flexibility upfront could be enough to significantly contribute to de-risk the project. Importantly, the literature review showed that the mathematical apparatus of real options theory was ill suited to support the design for evolvability problem, which involves a large number of relatively mundane design decisions. The analysis of the experiment results, which explored the plausibility of introducing a formal design for evolvability framing at project front-end strategizing, was encouraging. From a satisfaction perspective, adding a layer for formalisation in the decision-making process did not receive excessive push back from the teams. If anything, the teams that were tasked to follow a structured way of approaching the design definition problem welcomed the approach. This is an important result because it suggests project teams welcome the introduction of some structure at the project front-end often characterized as the fuzzy front-end (Smith & Reinertsen, 1998) due to the lack of structure for supporting this stage.

The experimental results also suggest that adding a design for evolvability framing at project front-end strategizing can improve the overall efficiency and effectiveness of this stage. From an efficiency perspective, a formal framing is important to create common ground amongst a wide range of project stakeholders that can often be expected to participate at the early project stages. These stakeholders come from very different backgrounds, have different technical capabilities and knowledge bases, and present huge asymmetry in their wherewithal to fund the project. Project front-end strategizing can often be inefficient because the participants fail to talk the same language and a lot of time is wasted before they can build a shared understanding of the problem, and of the main objectives that need to be accomplished at that stage. By structuring the early conversations through a formal design for evolvability, the teams can become more efficient and the quality of the conversation improves. The process efficiency is crucial to improve the outcomes of front-end strategizing and ensure its effective if time is a scarce resource.

Importantly, the design for evolvability framing does not introduce a counter-intuitive approach to design decision-making. Therefore, it is likely that a team going through an unstructured process, provided that they can afford the time, may accomplish results that are similar to those of the teams that followed a design for evolvability approach. Ultimately, formalising design for evolvability framing is not a proposition that introduces a structure fundamentally dissimilar to the way project teams intuitively make decisions at front-end strategizing. By helping project teams to be more efficient, however, a formal framing can help project teams to be also more effective because they need less time to achieve the ultimate objective. The results indicate that indeed a formal framing helped teams to produce more effective results in that they produced more solid recommendations in regards to the intertwinement between design optionality and capital funding. Whereas an unaided team may agree in principle that designing options is beneficial, the lack of structure can become a major impediment to resolve the difficult issues around how to fund optionality in a multi-stakeholder environment. In contrast, a formal framing provides a structure to help the multi-stakeholder teams overcome the difficult conversations around money and optionality. This is important because it is relatively straightforward to recommend investments in optionality through modularity and safeguards. It is significantly less straightforward to hammer out deals in regards to how these investments can be funded in a multi-stakeholder environment.

One last insight from this study is the importance of a formal framing for accountability purposes. There have been multiple calls to improve the transparency and accountability of decision-making in large-scale infrastructure projects (Flyvbjerg et al., 2003). These calls have been mainly motivated by observations that costs of capital projects more often than not spiral throughout delivery around the world. The debates have however been inconclusive in part because the studies lack depth. Based on some statistical studies, some authors argue that cost escalation in large-scale infrastructure projects is primarily due to strategic misrepresentation and optimistic bias (Flyvbjerg, 2009). Others argue that cost escalation can also be explained in part due to technical mistakes and evolution of project scope under conditions of uncertainty (Love, Edwards, & Irani, 2012). Irrespectively of which side one takes on the debate, it is unarguable the need to improve accountability for strategic decisions made at project front-end strategizing. This study responds to this call.

The method to design for evolvability encourages multiple stakeholders to reflect at the early stages on who should be paying for the additional investment in design flexibility and the reasons behind that decision. These investments in flexibility do not come for free. Nevertheless, they can be crucial to limit the costs to adapt the project scope if foreseeable uncertainties resolve favourably in the middle of the project delivery. They also come with risks that the investment will not pay off if the options are not exercised in the future. By formalising the decision-making process for incorporating – or deciding to rule out – options in the design definition, the new framing makes project teams accountable for the decision. A formal framing also contributes to make the whole decision-making process more transparent. The experimental results show that by institutionalising design optionality, the outcomes of front-end strategizing become less contingent on the particular capabilities of the individuals attending the meeting to rhetorically argue pro or against the incorporation of options. One of the case studies, for example, revealed instances where flexibility decisions were entirely contingent on the strong personality and rhetoric of one individual. Another example showed that the whole decision to invest in optionality changed after an experienced individual became involved in informal optionality discussions. In contrast, the results of the experiments show that a new framing contributes to attenuate the effect of these personalities and rhetoric of those attending the front-end meetings on the outcomes of the front-end strategizing process.

Importantly, improving accountability and transparency at front-end strategizing also matters to improve intergenerational equity, a fundamental issue at the heart of design for evolvability. Failure to invest in optionality at front-end strategizing not only lead to problems of cost escalation during project delivery if the scope has to change. Lack of optionality built-in can also create unnecessary major difficulties for subsequent generations in charge of operating the asset if the uncertainties resolve favourably in the future. At the limit, endorsing a rigid architecture that is prohibitively costly to adapt to foreseeable changes in the environment can create risks of premature technical obsolescence. At the same time, it would also be unfair to judge the project teams ex-post without understanding the constraints that they faced at the time when they needed to make front-end design decisions. Societies want to ensure decision–makers at front-end strategizing are made accountable for the decisions and judgment calls they take. Society also wants to ensure decision-making accounts for the contextual conditions when the judgement calls had to be made. The research findings suggest that a formal framing contributes to improve accountability at front-end strategizing because it helps to improve the quality of the documents recording the front-end conversations and the rationale for making optionality decisions. This is important to ensure front-end strategizing attends to the issues of intergenerational equity, which are inherent to this stage.

## References


Agresti, A., & Finlay, B. (1997). *Statistical methods for the social sciences*. Pearson Prentice Hall.

Alessandri, T. M., Ford, D. N., Lander, D. M., Leggio, K. B., & Taylor, M. (2004). Managing risk and uncertainty in complex capital projects. *The Quarterly Review of Economics and Finance*, *44*(5), 751–767. doi:10.1016/j.qref.2004.05.010

Amram, M., & Kulatilaka, N. (1999). *Real options: managing strategic investment in an uncertain world* (p. 246). Boston: Harvard Business School Press.

Anderson, C. A., Lindsay, J. J., & Bushman, B. J. (1999). in the Psychological Laboratory : Truth or Triviality ?, *8*(1), 3–9.

Angelou, G. N., & Economides, A. a. (2008). A Decision Analysis Framework for Prioritizing a Portfolio of ICT Infrastructure Projects. *IEEE Transactions on Engineering Management*, *55*(3), 479–495. doi:10.1109/TEM.2008.922649

Argyris, C., Putnam, R., & Smith, D. M. (1985). *Action Science: Concepts, Methods, and Skills for Research and Intervention*. San Francisco: Jossey-Bass.

Baldwin, C. Y. (2012). Organization Design for Business Ecosystems. *Journal of Organization Design*, *1*(1), 20–23. doi:10.7146/jod.2012.1.7

Baldwin, C. Y., & Clark, K. B. (2000). *Design rules: The power of modularity* (Vol. 1). Cambridge, MA: MIT Press.

Barlow, J., & Köberle-Gaiser, M. (2008). The private initiative, project form and design innovation: The UK's hospitals programme. *Research Policy*, *37*(8), 1392–1402.

BBC. (2012). Upton-upon-Severn flood defences unveiled. Retrieved July 13, 2012, from http://www.bbc.co.uk/news/uk-england-hereford-worcester-18817137

Bechky, B. A. (2012). Gaffers , Gofers , and Grips : Role-Based Coordination in Temporary Organizations. *Organization Science*, *17*(1), 3–21.

Beesemyer, J. C., Ross, A. M., Fulcoly, D. O., & Rhodes, D. H. (2011). Developing Methods to Design for Evolvability: Research Approach and Preliminary Design Principles. *9th Conference on Systems Engineering Research* (pp. 1–

12). Retrieved from http://seari.mit.edu/documents/preprints/BEESEMYER_CSER11.pdf

Biddle, B. (1986). Recent development in role theory. *Annual review of sociology*, *12*(1), 67–92. doi:10.1146/annurev.soc.12.1.67

Biernacki, P., & Waldorf, D. (1981). Snowball sampling: Problems and techniques of chain referral sampling. *Sociological Methods & Research*, *10*(2), 141. doi:10.1177/004912418101000205

Black, F., & Scholes, M. (1973). The Pricing of Options and Corporate Liabilities. *The journal of political economy*, *81*(3), 637–654. Retrieved from http://www.jstor.org/stable/10.2307/1831029

Block, S. (2007). Are "Real Options" Actually Used in the Real World? *The Engineering Economist*, *52*(3), 255–267. doi:10.1080/00137910701503910

Borison, A. (2005). Real options analysis: where are the emperor's clothes? *Journal of applied corporate finance*, *17*(May 2003). Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6622.2005.00029.x/abstract

Bowman, E. H., & Moskowitz, G. T. (2001). Real options analysis and strategic decision making. *Organization Science*, *12*(6), 772–777.

Brennan, M., & Schwartz, E. (1985). evaluating natural resource investments. *Journal of business*, *58*(2), 135–157. Retrieved from http://www.jstor.org/stable/10.2307/2352967

British Standards. (1988). *BS 5400-1:1988 - Steel, concrete and composite bridges. General statement*. (B. Standard, Ed.).

Bryman, A., & Bell, E. (2007). *Business Research Methods* (p. 786). Oxford University Press.

Bucciarelli, L. (1994). Delta Design Game. Cambridge: MIT.

Busby, J. S., & Pitts, C. G. C. (1997). Real options in practice : an exploratory survey of how finance of ficers deal with flexibility in capital appraisal, (December 1995), 169–186.

Campbell, D. T. (1957). Factors relevant to the validity of experiments in social settings. *psycological bulletin*, *54*(4), 297–312.

Cardin, M.-A., Kolfschoten, G. L., Frey, D. D., Neufville, R., Weck, O. L., & Geltner, D. M. (2012). Empirical evaluation of procedures to generate flexibility in engineering systems and improve lifecycle performance. *Research in Engineering Design*. doi:10.1007/s00163-012-0145-x

Chapman, C., & Ward, S. (2003). *Project risk management: processes, techniques and insights*. Chichester, UK: John Wiley & Sons.

Cleland, D. I., & King, W. R. (1983). *Systems analysis and project management* . New York: McGraw-Hill.

Cooper, D., & Chapman, C. (1987). *Risk Analysis for Large Projects: Models, Methods, and Cases*. Chichester, UK: Wiley, John & Sons, Incorporated.

Copeland, T, & Tufano, P. (2004). A real-world way to manage real options. *Harvard business review*. Retrieved from http://cours2.fsa.ulaval.ca/cours/gsf-64901/HBR_Copeland_March 2004.pdf

Copeland, Tom, & Antikarov, V. (2001). *Real Options: A Practitioner's Guide*. London: Texere.

Cox, J., Ross, S., & Rubinstein, M. (1979). Option pricing: A simplified approach. *Journal of financial Economics*, *7*(3), 229–263. doi:10.1016/0304-405X(79)90015-1

Croson, R., Anand, J., & Agatwa, R. (2007). Using experiments in corporate strategy research. *European Management Review*, *4*, 173–181.

Dallas, M. (2006). *Management Value and Risk Management A guide t o best practice*. *Main*. Oxford: Blackwel.

Davis, F. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, *13*(3), 319–340. Retrieved from http://www.jstor.org/stable/10.2307/249008

Dixit, A. (1992). Investment and hysterisis. *Journal of Economics Perspectives*, *6*(1), 107–132.

Dixit, A. K., & Pindyck, R. S. (1994). *Investment under uncertainty* (p. 468). Princeton: Princeton University Press.

Driouchi, T., Leseure, M., & Bennett, D. (2009). A robustness framework for monitoring real options under uncertainty☆. *Omega*, *37*(3), 698–710. doi:10.1016/j.omega.2007.09.004

El-Tayeh, A., & Gil, N. (2007). Using digital socialization to support geographically dispersed AEC project teams. *Journal of construction engineering and …*, *133*(6), 462–473. Retrieved from http://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-9364(2007)133%3A6(462)

Fichman, R., Keil, M., & Tiwana, A. (2005). Beyond valuation: Options Thinking in IT Project MAnagement. *Option Thinking" in IT …*, *47*(2). Retrieved from http://tiwana.myweb.uga.edu/pdfs/j/Fichman-Keil-TiwanaCMR2004.pdf

Flyvbjerg, B. (2009). Survival of the unfittest: why the worst infrastructure gets built--and what we can do about it. *Oxford Review of Economic Policy*, *25*(3), 344–367. doi:10.1093/oxrep/grp024

Flyvbjerg, Bent, Bruzelius, N., & Rothengatter, W. (2003). *Megaprojects and Risk: An Anatomy of Ambition* (p. 221).

Folmer, E., & Bosch, J. (2004). Architecting for usability: a survey. *Journal of Systems and Software*, *70*(1-2), 61–78. doi:10.1016/S0164-1212(02)00159-0

Ford, D. N., Lander, D. M., & Voyer, J. J. (2002). A real options approach to valuing strategic flexibility in uncertain construction projects. *Construction Management and Economics*, *20*(4), 343–351.

Ford, D. N., & Sobek, D. K. (2005). Adapting real options to new product development by modeling the second Toyota paradox. *IEEE Transactions on Engineering Management*, *52*(2), 175–185.

Gagliardi, M., Rajkumar, R., & Sha, L. (1996). Designing for evolvability: building blocks for evolvable real-time systems. *Proceedings Real-Time Technology and Applications* (pp. 100–109). IEEE Comput. Soc. Press. doi:10.1109/RTTAS.1996.509527

Gil, N., Tommelein, I.D., Schruben, L.W. (2006). External Change in Large Engineering Design Projects: The Role of the Client. IEEE Transactions on Engineering Management, 53 (3) 426-439.

Gil, N, & Beckman, S. (2007). Design Reuse and Buffers in High-tech Infrastructure Development: A Stakeholder Perspective. *IEEE Transactions on Engineering Management*, *54* (3), 484–497.

Gil, N, Beckman, S., & Tommelein, I. (2008). Upstream problem solving under uncertainty and ambiguity: Evidence from airport expansion projects. *… , IEEE Transactions on*, (1), 1–37. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4534701

Gil, Nuno. (2007). On the value of project safeguards: embedding real options in complex products and systems. *Research Policy*, *36*, 980–999.

Gil, Nuno. (2009a). Evolvable or “future-proof” infrastructure design: integrating modularity and safeguards. *Open Building Manufacturing: Key Technologies, Applications and Industrial Cases*.

Gil, Nuno. (2009b). Project Safeguards: Operationalizing Option-Like Strategic Thinking in Infrastructure Development. *IEEE Transactions on Engineering Management*, *56*(2), 257–270. doi:10.1109/TEM.2009.2016063

Gil, Nuno, & Beckman, S. (2009). Infrastructure Meets Business: Building New Bridges, Mending Old Ones. *California Management Review*, 6–29.

Gil, Nuno, Miozzo, M., & Massini, S. (2012). The innovation potential of new infrastructure development: An empirical study of Heathrow airport’s T5 project. *Research Policy*, *41*(2), 452–466.

Gil, Nuno, & Tether, B. (2011a). Design Flexibility and Risk Management: Substitutes or Complements? Insights from Heathrow’s Terminal 5 Project.

Gil, Nuno, & Tether, B. S. (2011b). Project risk management and design flexibility: Analysing a case and conditions of complementarity. *Research Policy*, *40*(3), 415–428. doi:10.1016/j.respol.2010.10.011

Gil, Nuno, Tommelein, I. D., & Schruben, L. W. (2006). External Change in Large Engineering Design Projects: The Role of the Client. *IEEE Transactions on Engineering Management*, *53*(3), 426–439. doi:10.1109/TEM.2006.877447

GMPTE. (2009). *SALFORD CRESCENT RAIL STATION REGENERATION APPRAISAL*.

Guma, A., Pearson, J., Wittels, K., Neufville, R. De, & Geltner, D. (2009). Vertical phasing as a corporate real estate strategy and development option. *Journal of Corporate Real Estate*, *11*(3), 144–157. doi:10.1108/14630010910985904

Highways Agency. (1992). BD 36/92 Design manual for roads and bridges. (T. H. Agency, Ed.).

Hillson, D., & Simon, P. (2007). *Practical Project Risk Management: The Atom Methodology* (management., p. 241).

Hornbæk, K. (2006). Current practice in measuring usability: Challenges to usability studies and research. *International Journal of Human-Computer Studies*, *64*(2), 79–102. doi:10.1016/j.ijhcs.2005.06.002

Howell, S., Stark, A., Newton, D., Paxson, D., Cavus, M., Azevedo-Pereira, J. A. de, & Patel, K. (2001). *Real options: evaluating corporate investment opportunities in a dynamic world* (p. 308).

Hughes, T. P. (1987). The evolution of large technological systems. In W. Bijker, T. P. Hughes, & T. E. Pinch (Eds.), *The Social Construction of Technological Systems* (pp. 51–82). Cambridge.

Hult, G. T. M., Craighead, C. W., & Ketchen Jr., D. J. (2010). Risk Uncertainty and Supply Chain Decisions: A Real Options Perspective. *Decision Sciences*, *41*(3), 435–458. doi:10.1111/j.1540-5915.2010.00276.x

Insead, R. A., & Levinthal, D. A. (2004). What is not a real option: considering boundaries for the application of real options to business strategy. *The Academy of Management Review*, *29*(1), 74–85.

ISO. (1998). Ergonomic requirements for office work with visual display terminals (VDTs). *International Standard*.

Kahkonen, K. (2006). Management of Uncertainty. In D. Lowe & R. Leiringer (Eds.), *Commercial Management of Projects: Defining the Discipline*. John Wiley & Sons.

Kalligeros, K. (2006). *Platforms and Real Options in Large-Scale Engineering Systems*. *Engineering Systems Division*. Massachusetts Institute of Technology, Massachusetts.

King, N. (2008). Template analysis. Retrieved from http://www.hud.ac.uk/hhs/research/template_analysis/

Klein, B., Meckling, W. (1957) Application of operations research to development decisions. Operations Research. 6, 352-363.

Knight, F. H. (1921). *Risk, uncertainty and profit*. (S. Press, Ed.) (p. 446). Iowa.

Kogut, B., & Kulatilaka, N. (2004). Response: Real Options Pricing and Organizations: The Contingent Risks of Extended Theoretical Domains. *The Academy of Management Review*, *29*(1), 102. doi:10.2307/20159012

Lander, D. M., & Pinches, G. E. (1998). Challenges to the practical implementation of modeling and valuing real options. *The Quarterly Review of Economics and Finance*, *38*(Special Issue), 537–567.

Laryea, S., & Hughes, W. (2011). Risk and Price in the Bidding Process of Contractors, (April), 248–258. doi:10.1061/(ASCE)CO

Lee, Y. S. (2007). *Flexible Design in Public Private Partnerships: A PFI Case Study in the National Health Service*. University of Cambridge.

Lenfle, S., & Loch, C. (2010). Lost Roots: How project management came to emphasize control over flexibility and novelty. *California Management Review*, *53*(1), 32–56.

Lewis, J. (2002). Psychometric Evaluation of the PSSUQ Using Data from Five Years of Usability Studies. *International Journal of Human-Computer Interaction*, *14*(3), 463–488. doi:10.1207/S15327590IJHC143&4_11

Lovallo, D., Kahneman, D. (2003). Delusions of success: how optimism undermines executives' decisions. *Harvard Business Review*, *81*(7), 57–63.

Love, P. E. D., Edwards, D. J., & Irani, Z. (2012). Moving Beyond Optimism Bias and Strategic Misrepresentation: An Explanation for Social Infrastructure Project Cost Overruns. *IEEE Transactions on Engineering Management*, *59*(4), 560–571.

Luenberger, D. (1998). *Investment Science*. Oxford: Oxford University Press.

MacMillan, I., Putten, A., McGrath, R. G., & Thompson, J. (2006). Using real options discipline for highly uncertain technology investments. *Research Technology Management*, *49*(1), 29–37.

March, J. G., & Simon, H. A. (1958). *Organizations* (p. 262). Wiley.

Maxwell, J. (2004). *Qualitative Research Design: An Interactive Approach* (p. 192). Sage Publications.

McConnell, J. B. (2007). A Life-Cycle Flexibility Framework for Designing, Evaluating and Managing “Complex” Real Options: Case Studies in Urban Transportation and Aircraft Systems. *Engineering Systems Division*. Massachusetts Institute of Technology.

McGrath, R. G. (1997). A real options logic for initiating technology positioning investments. *The Academy of Management Review*, *22*(4), 974–996.

McGrath, R. G., & MacMillan, I. C. (1995). Discovery Driven Planning. *Harvard Business Review*, *73*(4), 44–54.

McGrath, R. G., & MacMillan, I. C. (2000). Assessing technology projects using real options reasoning. *Research Technology Management*, *43*(4), 35–49.

Mcgrath, R. G., & Nerkar, A. (2004). REAL OPTIONS REASONING AND A NEW LOOK AT THE R & D INVESTMENT STRATEGIES OF PHA ...

McGrath, R. G., & Nerkar, A. A. (2004). Real options reasoning and a new look at the r&d investment strategies of pharmaceutical firms . *Strategic Management Journal*, *25*, 1–21.

Meredith, J. R., & Mantel, S. J. (2010). *Project management : a mangerial approach*. *Wiley series in production/operations management* (p. cm.). New York: Wiley.

Merna, T., & Al-Thani, F. F. (2005). *Corporate risk management* (John Wiley., p. 440). Chichester, UK.

Merton, RC. (1998). Applications of option-pricing theory: twenty-five years later. *American Economic Review*, *88*(3), 323–349. Retrieved from http://www.jstor.org/stable/10.2307/116838

Merton, Robert. (1973). Theory of Rational Option Pricing. *The Bell Journal of Economics and Management Science*, *4*(1), 141–183.

Metcalf, G. E., & Hassett, K. A. (1995). Investment under alternative return assumptions Comparing random walks and mean reversion. *Journal of Economic Dynamics and Control*, *19*(8), 1471–1488.

Miller, K. D., & Waller, G. (2003). Scenarios, real options and integrated risk management. *Long Range Planning*, *36*, 93–107.

Miller, R., & Lessard, D. (2000). *The strategic management of large engineering projects*. Cambridge, MA: The MIT Press.

Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. *International Journal of Project Management*, *19*(8), 437–443.

Miller, R., & Lessard, D. (2007). Evolving Strategy: Risk Management and the Shaping of Large Engineering Projects.

Morris, P., & Hough, G. H. (1987). *The Anatomy of Major Projects: A Study of the Reality of Project Management* (p. 338). John Wiley & Sons.

Morris, P. W. G. (1994). *The management of Projects*. London: Thomas Telford.

Morris, P. W. G. (2011). A brief history of project management. *The oxford handbook of project management* (pp. 15–36).

Nagali, V., Hwang, J., Sanghera, D., Gaskins, M., Pridgen, M., Thurston, T., Mackenroth, P., et al. (2008). Procurement Risk Management (PRM) at

Hewlett-Packard Company. *Interfaces*, *38*(1), 51–60. doi:10.1287/inte.1070.0333

Netwrok Rail. (2007). *North West Route Utilisation Strategy*.

Neufville, R. De. (2008). Using flexibility to improve value-for-money in hospital infrastructure investments. *Infrastructure Systems and …*, *44*(0). Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5439668

Neufville, R. de, Hodota, K., Sussman, J., & Scholtes, S. (2008). Real Options to Increase the Value of Intelligent Transportation Systems. *Transportation Research Record: Journal of the Transportation Research Board*, (2086), 40–47.

Neufville, R. de, & Scholtes, S. (2011). *Flexibility in Engineering Design*. MIT Press.

Neufville, R. de, Scholtes, S., & Wang, T. (2006). Real options by spreadsheet: parking garage case example. *Journal of Infrastructure Systems*, *12*(2), 107–111.

Peng, C., Erhun, F., Hertzler, E. F., & Kempf, K. G. (2012). Capacity Planning in the Semiconductor Industry: Dual-Mode Procurement with Options. *Manufacturing & Service Operations Management*, *14*(2), 170–185. doi:10.1287/msom.1110.0361

Phillips, R. (2003). *Stakeholder Theory and Organizational Ethics*. Berrett-Koehler Pub.

Pich, M. T., Loch, C. H., & Meyer, A. De. (2002). On Uncertainty , Ambiguity , and Complexity in Project Management. *Management Science*, *48*(8), 1008–1023.

PMI. (2004). *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*.

Putten, A. B. Van, & Macmillan, I. C. (2009). *Unlocking Opportunities for Growth: How to Profit from Uncertainty While Limiting Your Risk* (p. 161). Pearson Education.

Rese, A., & Baier, D. (2007). Deciding on new products using a computer-assisted real options approach. *International Journal of Technology Intelligence and Planning*, *3*(3), 292–303.

Ryan, P. A., & Ryan, G. P. (2002). Capital Budgeting Practices of the Fortune 1000 : How Have Things Changed ?, *8*(4).

Sauro, J., & Kindlund, E. (2005). A method to standardize usability metrics into a single score. *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI ’05*, 401. doi:10.1145/1054972.1055028

Shenhar, A., Dvir, D. (2007). Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation. Boston, MA: Harvard Business School Press, (288p).

Siegel, D. R., Smith, J. L., & Paddock, J. L. (1987). Valuing Offshore Oil Properties with Option Pricing Models. *Midland Corporate Finance Journal*, 22–30.

Smit, H. T. J., & Trigeorgis, L. (2004). *Strategic Investment: Real Options and Games*. Oxfordshire, UK: Princeton University Press.

Smith, J. E., & Nau, R. F. (1995). Valuing Risky Projects: Option Pricing Theory and Decision Analysis. *Management Science*, *41*(5), 795–816. doi:10.1287/mnsc.41.5.795

Smith, P. G., & Reinertsen, D. G. (1998). *Developing Products in Half the Time: New Rules, New Tools*. John Wiley & Sons.

Sreeves, J. (2007). Future-proof: Upton-upon-Severn viaduct, UK. In T. T. S. LTDA (Ed.), *Civil Engineering* (pp. 33–38). ICE.

Stonier, J. (2001). The change process. In Tom Copeland & V. Antikarov (Eds.), *Real options: A practitioner’s guide* (pp. 28–55). New York: Texere.

Suh, E. S., Weck, O. L. de, & Chang, D. (2007). Flexible products platform: framework and case study. *Research in Engineering Design*, *18*, 67–89.

Taylor, P., Garvin, M. J., & Ford, D. N. (2012). Real options in infrastructure projects : theory , practice and prospects Real options in infrastructure projects : theory , practice and prospects, (January), 37–41.

Terwiesch, C., & Xu, Y. (2004). The Copy-Exactly Ramp-Up Strategy: Trading-Off Learning With Process Change. *IEEE Transactions on Engineering Management*, *51*(1), 70–84. doi:10.1109/TEM.2003.822465

Thomke, S., & Fujimoto, T. (2000). The Effect of “Front-Loading” Problem-Solving on Product Development Performance. *Journal of Product Innovation Management*, *17*(2), 128–142.

Tiwana, A., Keil, M., & Fichman, R. G. (2006). Information Systems Project Continuation in Escalation Situations : A Real Options Model. *Decision Sciences*, *37*(3), 357–391.

Triantis, A., & Borison, A. (2000). REAL OPTIONS : STATE OF THE PRACTICE.

Trigeorgis, L. (1996). *Real Options, Managerial Flexibility and Strategy in Resource Allocation*. Cambridge, MA: MIT Press.

Trigeorgis, L., & Smit, H. T. J. (2009). Valuing infrastructure investment: an option games approach. *California Management Review*, *51*(2), 79–100.

Trochim, W. M. K. (2006). *Research methods knowledge base* (p. 361). Cincinnati: Atomic Dog.

Vaidyanathan, V., Metcalf, D., & Martin, D. (2005). Using Capacity Options to Better Enable Our Factory Ramps. *Intel Technology Journal*, *9*(3).

Wang, T., & De Neufville, R. (2005). Real options “in” projects. *9th Annual International Conference Real Options*. Paris, France.

Williams, T. M., Samset, K., & Sunnevåg, K. J. (2009). *Making Essential Choices with Scant Information: Front-end Decision Making in Major Projects*. Palgrave Macmillan.

Wilmott, P., Howinson, S., & Dewynne, J. (1995). *The mathematics of financial derivatives : a student introduction*. Cambridge: Cambridge University Press.

Winch, G. M., & Maytorena, E. (2011). Managing Risk and Uncertainty on Projects: A Cognitive Approach. *The oxford handbook of project management* (pp. 345–364).

Yin, R. K. (2003). *Case Study Research: Design and Methods* (Third Edit.). London: Sage Publications.

Zhao, T., Sundararajan, S. K., & Tseng, C.-L. (2004). Highway development decision-making under uncertainty: a real options approach. *Journal of Infrastructure Systems*, *10*(1), 23–32.

## Appendix A: Interview protocol

Core research questions for one-on-one interviews

I. Introduction: Professional activities in the company/organisation

1. Job role?
2. Company vision and interests
3. Company background
4. Knowledge about railways projects
5. Capital projects involved?
6. Participation in meetings with NR

II. Background Exploration: Understanding and involvement of the project

7. Importance of the project to the company
8. Financial contribution to the project
9. Similar project executed previously
10. Interdependence with other projects
11. Bargain power

III. On specific Projects

12. Characterize uncertainty in project requirements
13. Characterize flexibility in design architecture
14. Characterize project delivery and operational lifecycle timescales
15. Characterize options built into design definition

IV. Focused Exploration: Requirements

16. Importance of future requirements
17. Does the project design cope with future requirements?
18. How future requirements are negotiated?
19. Who pays for those requirements?

# Appendix B: Questionnaire to Assess Overall Satisfaction with the Front-end Strategizing Process

*In the next set of questions you are presented with a number of statements. Please indicate your level of agreement with each statement (1=strongly agree, 7=strongly disagree).*

| | |
|---|---|
| **System usefulness** | |
| 01 – Overall, I am satisfied with how easy it was to front-end strategize the project | |
| 02 – It was simple to do the project front-end strategizing | |
| 03 – I could effectively complete the project front-end strategizing | |
| 04 - I was able to complete the tasks and scenarios quickly | |
| 05 - I was able to efficiently complete the tasks and scenarios | |
| 06 - I felt comfortable with the project front-end strategizing process | |
| 07 - It was easy to learn how to project front-end strategize | |
| 08 - I believe I could NOT become more productive in project front-end strategizing | |
| **Information quality** | |
| 09 – The information received as institutional support clearly helped us to fix problems | |
| 10 - Whenever there were disagreements among participants, the information helped to overcome them easily and quickly | |
| 11 – The information received as part of the institutional support was adequate | |
| 12 – It was easy to leverage the information received as part of the institutional support | |
| 13 - The information received as part of the institutional support was easy to understand | |
| 14 - The information received as part of the institutional support was effective in helping us complete the tasks and scenarios | |
| 15 - The institutional support was well structured | |
| **Interface quality** | |
| 16 - The institutional support was easy to access | |
| 17 - I liked undertaking this project front-end strategizing with the level of institutional support that was provided | |
| 18 – The institutional support provided had all the qualities that I expect it to have | |
| 19 - Overall, I am satisfied with the institutional support that was provided | |

Please add any other comments you may have regarding this exercise

# Appendix C: Instructor's Guide

The front-end strategizing exercise consists of a lab-based simulation of the 'fuzzy' front-end strategizing process for a real-world project, the redevelopment of Network Rail (NR)'s Salford Crescent Railway Station. The exercise is designed to be undertaken with graduate-standing students enrolled in engineering and management programmes. Its aim is to make students aware of the multi-stakeholder nature of the front-end strategizing process for a new infrastructure development (capital) project. The exercise creates an opportunity for students to experience a major challenge invariably facing multi-stakeholder teams at the project onset: reach a multilateral agreement on a design concept that can cope with foreseeable evolution in design requirements over the project and operating live. This requires the stakeholders to collectively balance affordability constraints with capital investments needed to 'future-proof' the asset, i.e., investments to design in provisions to build flexibility in the asset definition. Getting this balance right is not straightforward for a number of reasons. First, stakeholders have different priorities, capabilities, and planning horizons; second, front-end strategizing talks are inexorably intertwined with negotiations on how to distribute the costs of the capital investments; and third, some stakeholders may not be in a position to contribute to fund a concept that meets their needs, but they may nonetheless find themselves legitimately entitled to make particular demands.

To play the exercise, the instructor needs to assemble teams of six participants, each one randomly assigned to play the role of a different stakeholder (see roles in Table 1). A week before the exercise, each student receives a set of instructions on how to play the allocated role including a generic design brief, a bespoken brief with information about their particular role, and ancillary information. Each team is then tasked to meet for a class session (~2 ½ hours) to discuss the pros and cons of a set of alternative concepts for the project and agree a design concept and funding strategy. At the end of the exercise, students will be asked to fill a questionnaire about how satisfied they were overall with the process. Filling the questionnaire, reproduced in Exhibit I, should not take students more than 5 minutes.

In the following session the instructor and students can debrief the experience, debate the extent to which the exercise reasonably simulates a real-world situation, and discuss any lessons relevant for multi-stakeholder teams facing the challenge of balancing short-term affordability with long-term adaptability. The instructor can use the results of the questionnaire, both quantitative data as well as students' written comments, to set off the discussion. As an option, the instructor can ask teams to submit formal written deliverables which can count for their final grade. For example, teams can be given 2 days after the meeting to produce and submit:
1. a strategic recommendation spelling out the characteristics of the design concept taking into consideration capital and adaptation costs, stakeholders'

priorities, affordability issues, and project timescales; and 2. a meeting minute documenting the rationale underpinning their strategic recommendation and any multilateral agreements reached for funding the project. Students can also be asked to write a 4-page reflective essay on the overall experience.

Table 1 – Project Stakeholder roles

| Role | Main objectives for project front-end strategizing | Ancillary information |
|---|---|---|
| NR Project Manager | 1. deliver the project on time and within the budget;<br>2. ensure concept meets the DfT High Level Output Specification<br>3. ensure concept fits with the National Stations Improvement Programme (NISP) policy | NR Route Utilisation Strategy for the North West |
| NR Project Engineer | 1. ensure concept meets the technical standards and regulations<br>2. ensure concept enables to deliver to budget and within the timescale | NR Route Utilisation Strategy for the North West |
| NR Commercial Sponsor | ensure concept meets the external stakeholders' interests, particularly those of the franchised station operator without compromising the NR commercial interests | NR Route Utilisation Strategy for the North West |
| University | 1.ensure the concept is aligned with the university's master plan<br>2. ensure the concept guarantees ease of access to the campus<br>3.ensure the concept encourages people to commute sustainably | University Campus master plan |
| Regeneration agency | ensure the concept produces an aesthetically pleasant station building ('landmark building') to support the local socio-economic development | Vision and Regeneration Local Framework |
| Station operator | ensure that the concept guarantees short-term revenue protection, whilst improving the reliability and friendliness of the train services and station | Station operator response to the NR North West RUS |

Importantly, to enrich the quality of the debriefing session and to better the learning experience, the instructor can set up two types of teams. Teams in the control group have to get their act together without receiving any additional form of institutional support beyond the archival documents they will get prior to the meeting – this by and large mimics the way front-end strategizing processes tend to occur in the real-world. In contrast, teams in the experimental group can be aided by a *Champion of Design for Evolvability*. The student allocated to this role will also be handed over a bespoken design brief with detailed instructions – Exhibit II provides a summary of these instructions.

Broadly, the role of the champion is to educate the team about the implications of ruling in and out provisions to build in options, highlighting that doing something relatively small now – provided the investment is affordable and sensible – may prevent much trouble later. The brief itself offers a design for evolvability protocol that teams can adopt, which formalises the use of options logic to resolve concept design at front-end strategizing. This protocol spells out a structured process to help the team decide, first, which provisions to cope with foreseeable uncertainties should be designed in the concept of a new asset with a long operational life, and second, how to distribute the capital costs. The Champion of Design for Evolvability is empowered to steer the multi-stakeholder team through the process that involves three stages, allowing for iterative loops: 1. Analysing Options, 2. Designing Alternatives, and 3. Project Strategizing. Each stage, in turn, encompasses a sequence of steps aimed at producing a deliverable that feeds into the next stage.

Exhibit I – Questionnaire to Assess Overall Satisfaction with the Front-end Strategizing Process

*In the next set of questions you are presented with a number of statements. Please indicate your level of agreement with each statement (1=strongly agree, 7=strongly disagree).*

System usefulness

01 – Overall, I am satisfied with how easy it was to front-end strategize the project

02 – It was simple to do the project front-end strategizing

03 – I could effectively complete the project front-end strategizing

04 - I was able to complete the tasks and scenarios quickly

05 - I was able to efficiently complete the tasks and scenarios

06 - I felt comfortable with the project front-end strategizing process

07 - It was easy to learn how to project front-end strategize

08 - I believe I could NOT become more productive in project front-end strategizing

Information quality

09 – The information received as institutional support clearly helped us to fix problems

10 - Whenever there were disagreements among participants, the information helped to overcome them easily and quickly

11 – The information received as part of the institutional support was adequate

12 – It was easy to leverage the information received as part of the institutional support

13 - The information received as part of the institutional support was easy to understand

14 - The information received as part of the institutional support was effective in helping us complete the tasks and scenarios.

15 - The institutional support was well structured

Interface quality

16 - The institutional support was easy to access

17 - I liked undertaking this project front-end strategizing with the level of institutional support that was provided

18 – The institutional support provided had all the qualities that I expect it to have.

19 - Overall, I am satisfied with the institutional support that was provided.

Please add any other comments you may have regarding this exercise

Exhibit II – The Design for Evolvability Protocol

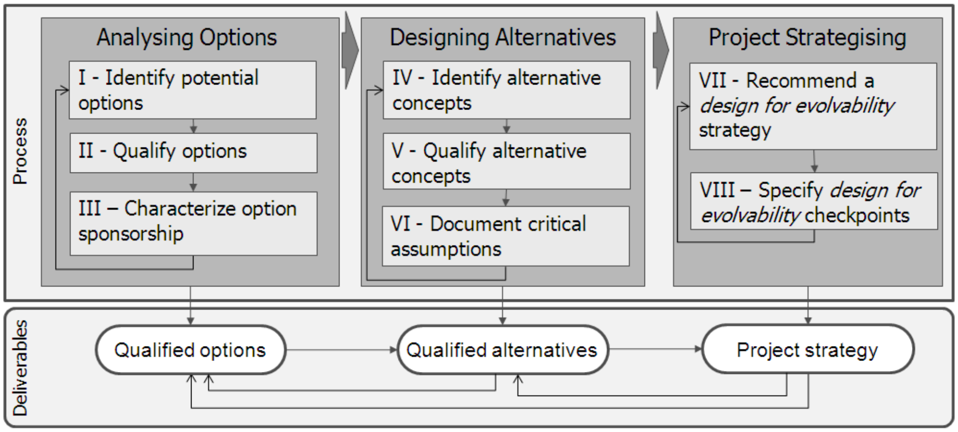



Figure II.1: Schematic representation of the design for evolvability protocol

In the first stage, Analysing Options, the project team has to identify potential options by looking at how their parent organisations' strategic visions translate into operating scenarios for the new asset, which in turn point to potential options to design in the concept. The team has to qualify these options attending to the variables and relationships in formal options logic, e.g., plausible ranges for the exercise and expiration dates, exercise likelihood, and value created if uncertainties resolve favourably. The team also has to characterize option sponsorship, a step crucial to start a conversation about which party is in a better position to fund the capital costs that need to be incurred to design in each option and incur the risk.

In the second stage, Designing Alternatives, the project team has to identify alternative concepts that vary in the extent to which the options previously identified are designed in, and accordingly vary in the capital and eventual adaptation costs. The team also has to characterise key design parameters for each alternative and for a baseline scenario (without built-in options). Hence, the team needs to assess whether integral architectures can be modularised, and if not, if flexibility can be built in through safeguards. Importantly, the aim is not to discuss how the alternatives address immediate needs, often the focus of conventional 'optioneering appraisals,' but rather to decide whether to design in options to cope with foreseeable change. To conclude this stage, the team needs to check sponsor commitment to fund the built-in options, and document any critical assumptions.

In the final stage, Project Strategizing, the team has to recommend a Design for Evolvability strategy as part of the front-end strategizing effort. The team has to agree collectively on a concept design with or without built-in options, and accordingly, agree on a funding strategy. The strategy should discuss capital and eventual adaptation costs, as well as option sponsorship. In addition, the team has to specify checkpoints for checking whether the underpinning assumptions remain valid or not in project time. The checkpoints need to be set up in a way that fits with the capital development process adopted by the leading party.

# Appendix D: Estimating Volatility from Historical Data

The volatility in the number of days of road closure is calculated in the same way the volatility of a stock price can be empirically obtained by observing fixed intervals of time (Hull 2008). Based on the records from the environment agency, Table 1 shows the number of days of road closure from 1988 to 2002 and the associated total costs ($C_t$) as a function of road closure.

| Year | Days of interruption ($D_c$) | Total cost ($C_t$) | Relative $C_t$ | Yearly return ($u_i$) | - | - |
|---|---|---|---|---|---|---|
| | | $(C_{div} + C_{local}) * D_c$ | $\frac{S_i}{S_{i-1}}$ | $\ln\left(\frac{S_i}{S_{i-1}}\right)$ | $u_i - \bar{u}$ | $\left(u_i - \bar{u}\right)^2$ |
| 1988 | 11.24 | £1,722,554.16 | | | | |
| 1989 | 11.46 | £1,757,005.25 | 1.020 | 0.020 | 0.014 | 0.000 |
| 1990 | 14.72 | £2,256,545.95 | 1.284 | 0.250 | 0.244 | 0.060 |
| 1991 | 10.67 | £1,636,426.46 | 0.725 | -0.321 | -0.327 | 0.107 |
| 1992 | 12.25 | £1,877,584.04 | 1.147 | 0.137 | 0.131 | 0.017 |
| 1993 | 12.25 | £1,877,584.04 | 1.000 | 0.000 | -0.006 | 0.000 |
| 1994 | 12.25 | £1,877,584.04 | 1.000 | 0.000 | -0.006 | 0.000 |
| 1995 | 11.80 | £1,808,681.87 | 0.963 | -0.037 | -0.044 | 0.002 |
| 1996 | 11.80 | £1,808,681.87 | 1.000 | 0.000 | -0.006 | 0.000 |
| 1997 | 11.80 | £1,808,681.87 | 1.000 | 0.000 | -0.006 | 0.000 |
| 1998 | 25.06 | £3,841,295.78 | 2.124 | 0.753 | 0.747 | 0.558 |
| 1999 | 11.80 | £1,808,681.87 | 0.471 | -0.753 | -0.759 | 0.577 |
| 2000 | 32.02 | £4,909,279.37 | 2.714 | 0.999 | 0.992 | 0.985 |
| 2001 | 32.02 | £4,909,279.37 | 1.000 | 0.000 | -0.006 | 0.000 |
| 2002 | 12.25 | £1,877,584.04 | 0.382 | -0.961 | -0.967 | 0.936 |
| | | | $\bar{u}$ | 0.006 | ∑ | 3.242 |

**Table 1: Calculation of volatility based on road interruption**

The yearly return ($u_i$) is calculated by:

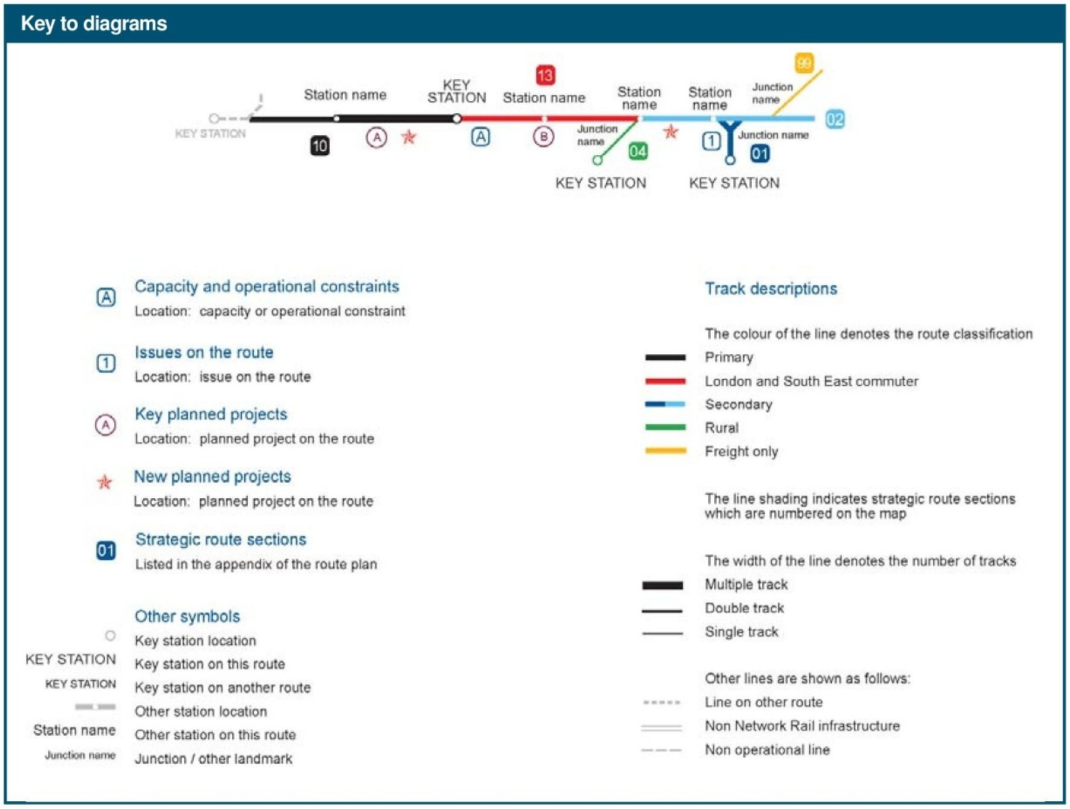
$$u_i = \ln\left(\frac{S_i}{S_{i-1}}\right) \quad (1)$$

The volatility is given by:

$$s = \sqrt{\frac{1}{n-1} * \sum \left(u_i - \bar{u}\right)^2} \quad (2)$$

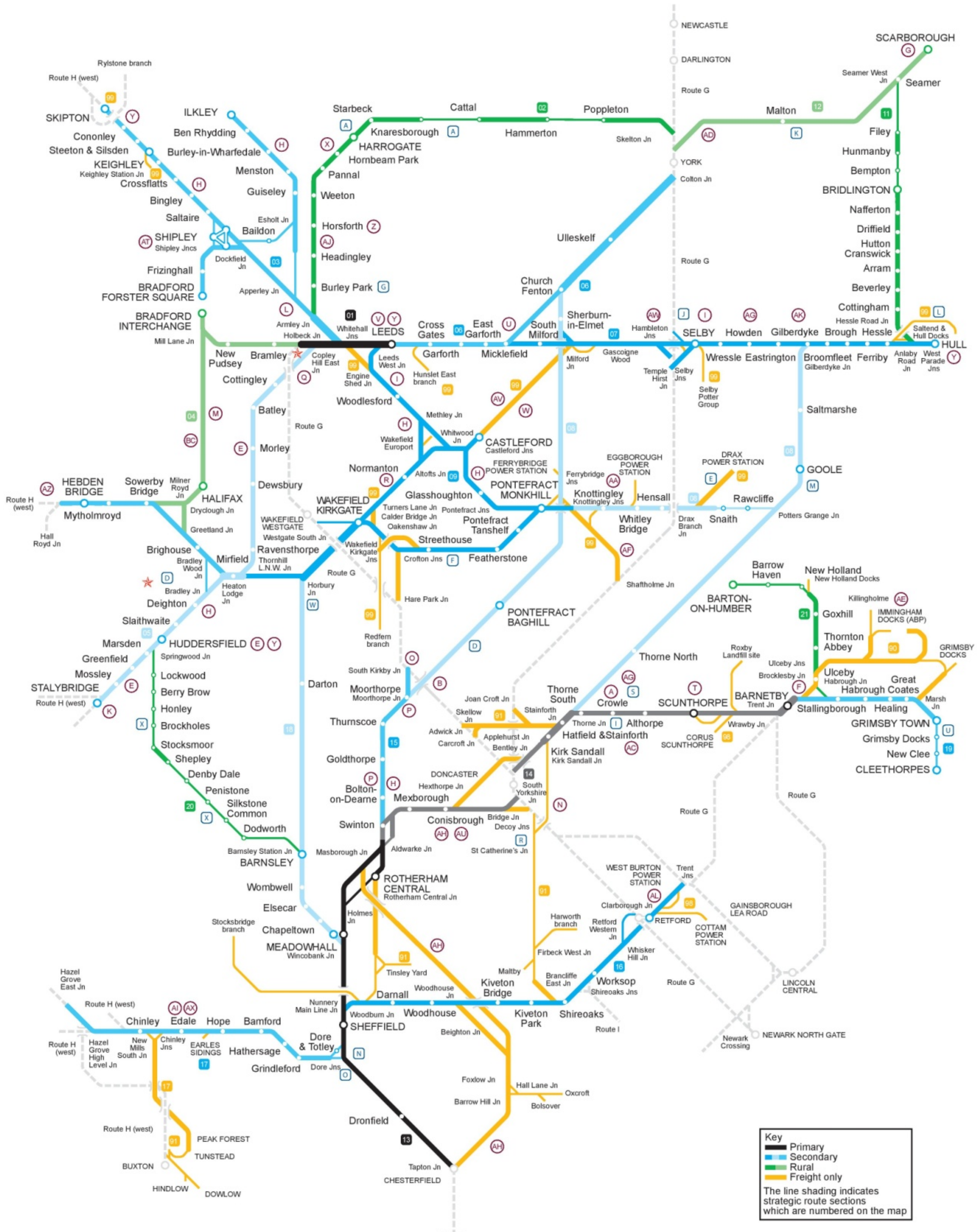
From eq 2 and 15 observations (n), the final volatility is 0.4812 or 48.12%.

## Appendix E: Route Map for Cross-Pennine, Yorkshire & Humber and North West

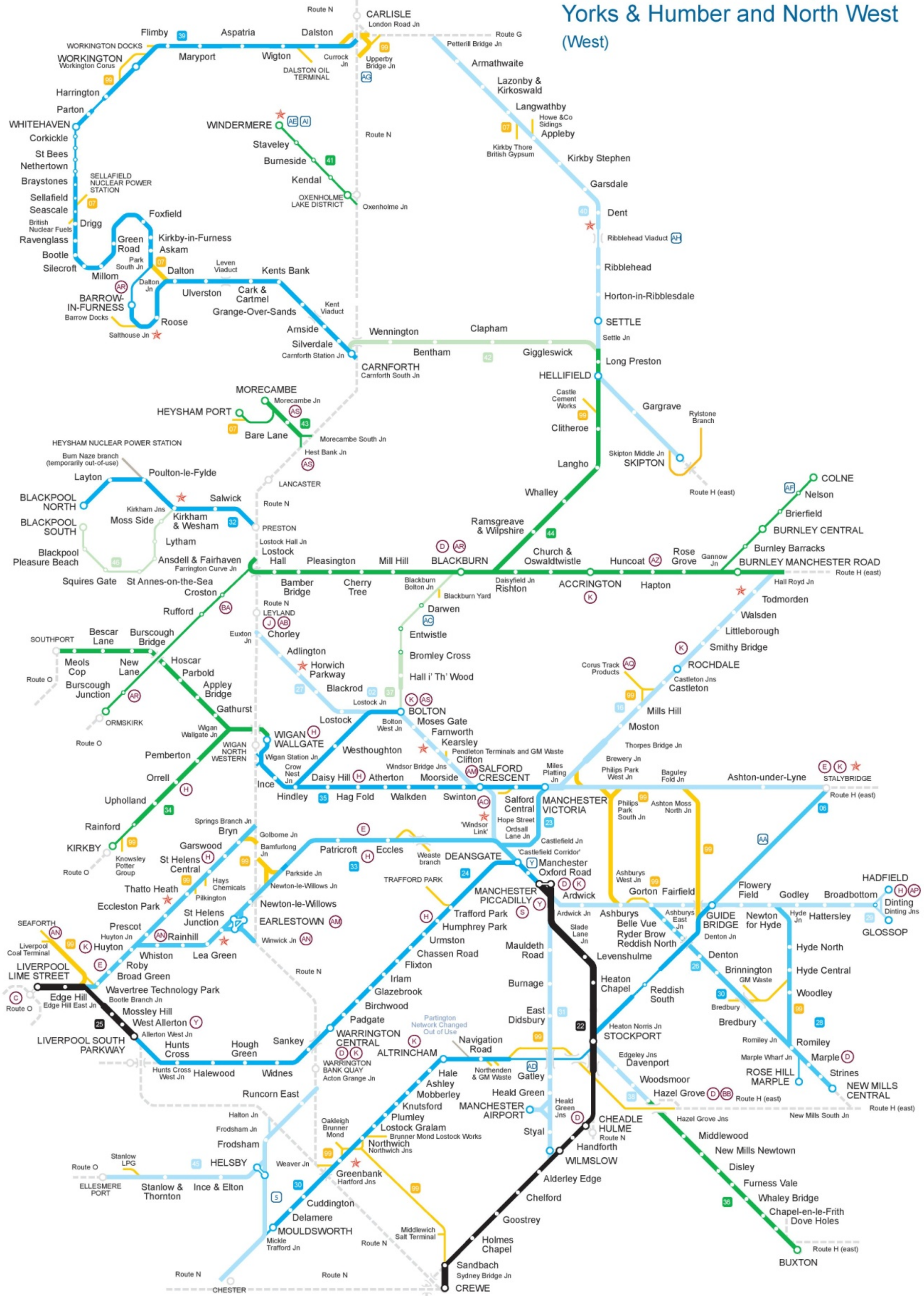


# **Route H** Cross-Pennine, Yorks & Humber and North West

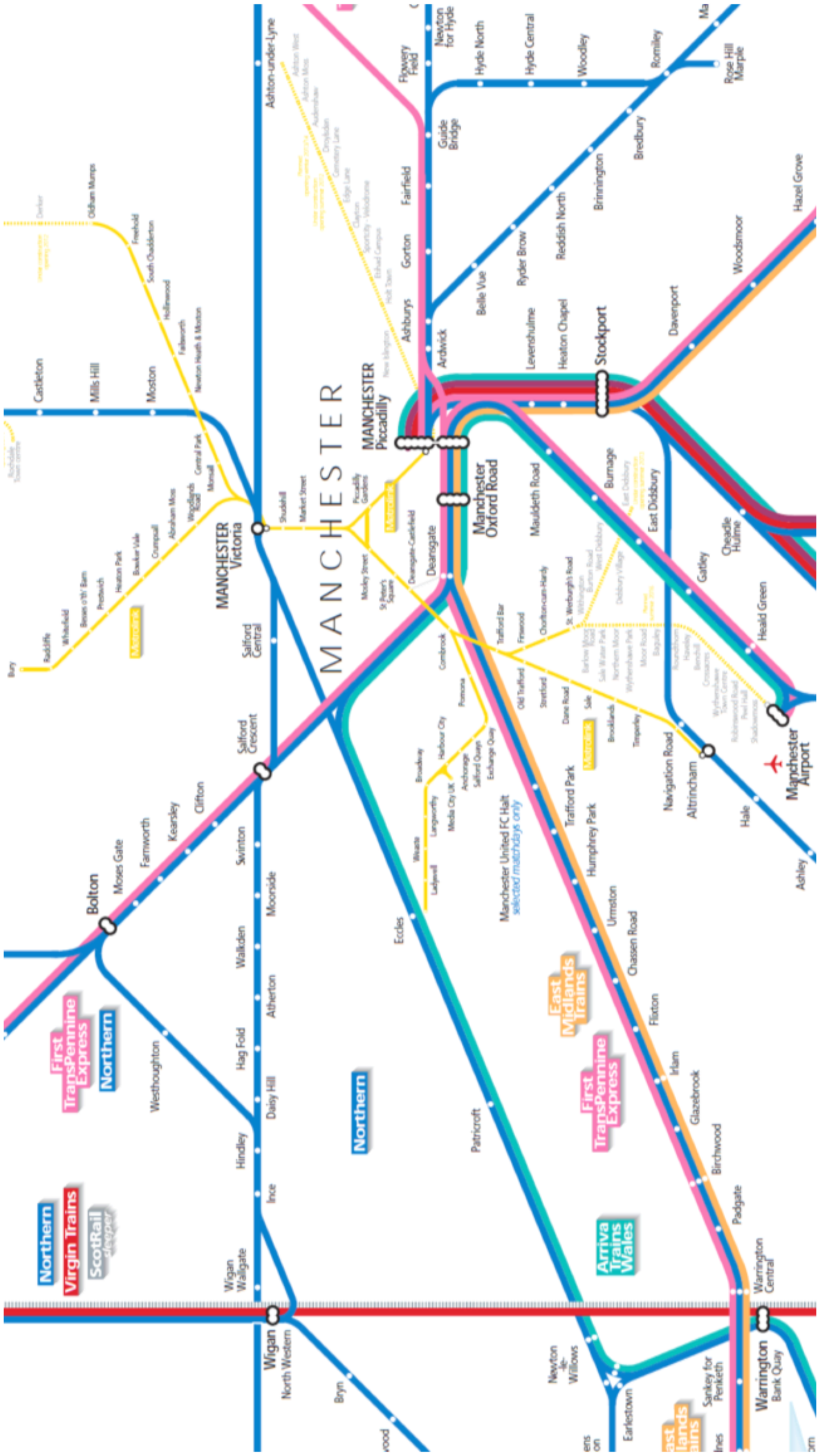
(East)



# Route H Cross-Pennine, Yorks & Humber and North West
(West)



# Appendix F: TOC franchises around the Salford Crescent Area



## Appendix G: Meeting Agenda

The following was the proposed agenda for the meeting, to be chaired by the Design for Evolvability, as nominated by Network Rail:

1. Call to order
2. Introductions
3. Analysing Options
    a. Identify Potential Options
    b. Qualify Options
    c. Characterise Option Sponsorship
4. Designing Alternatives
    a. Identify Alternative Concepts
    b. Qualify Alternative Concepts
    c. Document Critical Assumptions
5. Project Strategizing
    a. Recommend a Design for Evolvability Strategy
    b. Specify Design for Evolvability Checkpoints
6. Conclusion