

Project Safeguards: Operationalizing Option-Like Strategic Thinking in Infrastructure Development

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Abstract—When business strategists use option-like thinking to inform investments in physical infrastructure, developers need to operationalize leaving the options open at project implementation. This study defines safeguard as the design and physical development work for ensuring, or enhancing, the embedment of an option in the project outcome. Safeguards account for design changes stemming from option exercising if the environmental uncertainties resolve favorably in the future. They range from a design effort to secure space in a master plan (passive) to the construction of an integral component (active). A multiple-case study on the expansion of Heathrow airport shows how the confluence of two contingencies underscores decisions to safeguard under a limited budget. Safeguarding is more attractive when: 1) the assumed uncertainty that the option will get in the money is low because the outlay sunk on safeguards is more likely to pay off; and 2) the infrastructure architecture is modular because only the interfaces between components may require safeguarding. Irreversible investments on safeguards increase the option cost and reduce the exercising costs in the future. Safeguards therefore play out as a control point for strategic option-like thinking at project implementation. The empirical findings are summarized in a conceptual framework.

Index Terms—Infrastructure design and development, project management, real options reasoning, strategy implementation, uncertainty.

I. INTRODUCTION

THE ESSENCE of option-like thinking posits that an early investment strategy can be used to gain advantage under high uncertainty about the future states of the world. Yet, it recognizes that firms have incentives to defer irreversible investments under uncertainty [4, 45, p. 332]. Uncertainty is a measure of the variability, or volatility, of the future returns of the underlying asset, i.e., the asset with the same risks as the project that the firm would own if the options were exercised [11]. The more the future is uncertain, or the value of the underlying risky asset is volatile, the more it pays to have a broad range of options open. The asymmetry in payoffs allows benefiting from higher upside movements while limiting losses on the downside [50, p. 92]. The value of an option also increases the longer the length of time the option can stay open since it represents more opportunities to collect information and

make choices. As events unfold, some options may not be worth pursuing, but others may be a blockbuster [45, p. 332].

An options framework fits well with strategic investments on physical infrastructure, such as airports or production plants, which are developed to operate over various decades despite uncertainty at the outset about the future [28], [32], [44]. The question underscoring this study is: how to best operationalize strategic option-like thinking at project implementation? Ensuring that options stay open in the design architecture of a new infrastructure seldom comes for free. Developers need to allocate the resources wisely when they are instructed by strategists to build in a range of options under a tight budget. The more resources developers spend for leaving one option open, the less they can use elsewhere in the development process. If developers do too little to ensure the option stays effectively open, however, it can be hard to economically exercise it in the future. Hence, developers face a problem of resource allocation under uncertainty with limited information on the strategic value of each option. Grounded in empirical data on the expansion of Heathrow airport (terminal 5), this study contributes a conceptual framework for helping project developers operationalize option-like strategic thinking.

II. PROJECT SAFEGUARDS

I term project safeguard to the design and physical development work needed for ensuring, or enhancing, the embedment of a real option in an infrastructure. A real option is the right, but not the obligation, to take an action such as expanding, acquiring, deferring, or abandoning, at a specified price (the exercising cost) for a predetermined period of time [11], [50]. A safeguard ensures that the architecture of the infrastructure can accommodate the foreseeable changes in the operational and functional requirements if the option gets exercised in the future. These are changes that decision-makers can speculate beforehand but cannot say exactly if and when they will occur [46]. When safeguards involve only a design effort, for instance, to secure space in a master plan layout, I define them as *passive*; safeguards are *active* if they also involve physical delivery of infrastructure components. Here, I investigate the factors underscoring decisions about: 1) whether to safeguard, and if so 2) what work needs to be done and how it affects the project budget. The irreversible investments on safeguards indicate what a firm loses if the options go unused.

A. Attractiveness of Safeguarding

The field study on safeguards systematically shows that their attractiveness hinges on the confluence of two factors at project implementation: First, the assumed uncertainty, from a

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developer's point-of-view, about whether the option will ever get into the money and be exercised. Developers are responsible for building into the infrastructure definition the options identified and documented by strategists. They have to do so under a limited budget. I empirically find that developers reason that an irreversible investment to safeguard an option with low (assumed) uncertainty that it will get in the money in the future makes more sense than an investment to safeguard an option with high uncertainty. Low uncertainty is often associated with short-range timeframes as the prospect of the future diverging from foreseeable scenarios increases as time progresses since fewer factors can be accurately known [41].

The intuitive rationale enacted by developers supports developments in project risk management, a discipline that grew out of expected utility theory (e.g., [7], [8]). The utility of an option is a function of the probability of that option occurring and the expected benefit of that option should it occur [52]. Likewise, risk is defined as the probability of an event occurring times the impact its occurrence may cause [39]. Risk expresses future occurrences whose variability can be modeled into reliable probability distributions, whereas uncertainty applies where knowledge is insufficient to do so [21]. Infrastructure developers trust on strategists to identify and document the options with greater expected benefits. Yet, they are unlikely to find information about probabilities of option exercising, or in other words, about the risks that the organization incurs if the options are not built in. Hence, they resort to foreseeable environmental uncertainties as a proxy for the assumed uncertainty of option exercising to inform safeguarding decisions.

I also empirically find that the attractiveness of safeguarding increases when the architecture of the infrastructure is modular. Modular product designs exhibit a one-to-one mapping from functional elements to physical subsystems and components, as well as decoupled interfaces between the elements [51]. Modular designs by definition exhibit built-in options. The standard interfaces allow the modules to evolve parametrically as long as changes conform to the design rules and integration protocols agreed upfront [5, p. 223]. Option-holders can exercise the options by substituting one module with a superior module, and by adding new modules.

While modularity is "tolerant of uncertainty" [45], safeguarding the interfaces between modules can further enhance the built-in options. The investment to safeguard the cross-module interfaces trades off with the future costs of integrating a new module [13]. Safeguarding modular architectures can be attractive because, first, it involves limited budget commitments; and second, the stability of the design rules [5] reduces the risk that safeguards become obsolete over time, i.e., technical uncertainty is low. To put it in risk management terms, modularity reduces *the expected impacts caused by the identifiable risks of exercising a range of options in the future.*

Of course, modularity does not come for free [5]. An overly investment on modularization involves costly cycling behavior that may not pay itself off through corresponding gains in performance improvement [13]. The cost of modularizing an integral design can occasionally be unaffordable. When the architecture

is integral, the cost to build in an option is much higher. In these circumstances, safeguarding is less attractive.

The remaining of this paper is structured as follows. After reviewing the related work (Section III), I describe the research methods and setting (Section IV). I then examine a theoretical sample of efforts to safeguard 12 options across five infrastructure projects (Section V). From these findings, I induce a framework on the attractiveness of safeguards and discuss the trade-offs (Section VI). Finally, I discuss the limitations (Section VII) and implications to practice and theory (Section VIII).

III. RELATED WORK

Real options refers to choices on whether and how to proceed with business investments [45]. Early applications of real options concepts date from the mid-1980s in natural resource investments, such as mining and offshore petroleum leases, as well as land development, government subsidies, and regulation [45, p. 106].

One branch of real options develops pricing models for evaluating options (e.g., [9], [16], [23], [40], [50]). The investment in an option makes economic sense when the option value exceeds its cost [6]. Quantification can be hard, however, when: 1) data predicting the business environment in the future are not reliable; 2) there is a portfolio of interrelated options in which the incremental value of each option increases or decreases whether it complements or substitutes other options [23]; and 3) the option value is path-dependent, as it happens in lengthy projects where it is difficult to economically switch between strategic paths [45]. The real options reasoning approach translates the mathematical, economic logic into a qualitative, heuristic mechanism to help firms make strategic investments ([20], [26]). Both approaches have matured over time, but empirical studies lack on the implementation issues [1].

Three types of options in Trigeorgis' taxonomy [50] relate to our study: 1) *Stage options* represent an option on the value to proceed to the next stage, in which the execution of the subsequent stage is made contingent on a reassessment of the costs and benefits of completing that stage at the time the stage is reached [50]. 2) *Growth options* build flexibility to increase capacity in response to future events that will make growth economically justifiable [48], [50]. 3) *Switch options* reflect a firm's willingness to pay a positive premium over a rigid alternative for a technology that can flex to different operational requirements through switching between production processes or outputs [50].

Differences in the assumptions underpinning the theories of evaluating financial and real options are at the core of a debate on the boundaries of applicability of real options [1], [22], [27]. Unlike financial options, the real option-holder can act endogenously to shape both the target markets and technical agendas, thereby influencing favorably the option value [45]. Adner and Levinthal [1] posit that this difference can undermine the timely abandonment of the option when uncertainties get resolved unfavorably because of organizational bias, vested interests of stakeholders, and lack of conformity to corporate policy and to the logic of governing a portfolio of options. Hence, the use of

real options may be inappropriate when firms lack rigid control systems and the outcomes on strategic opportunities are linked to firm action [1]. Yet, others argue that firms need to consider endogenous actions in their valuation models and proactively manage implementation to preclude misuse of the theory [22], [27]. Out of this debate, project management emerges as a suitable environment to “translate” [22] financial pricing theory into real options. Project control systems can dissuade over irreversible investment when firms can act endogenously to affect the future. Project systems can also avoid that options “take a life of their own” [1].

Research on the application of option-like thinking to project management is not new (e.g., [34], [37], [54]). Early normative studies build upon the dichotomy between risk and uncertainty. They suggest incorporating areas of incomplete knowledge [37], possibility theory [34], and the value of managing flexibility [54] into probability-based risk management theory and practice manuals. Other studies focus on evaluating project management options, including the option of corrective action [19], the abandonment option [14], and growth options [48]. More recently, Fichman *et al.* [15] discuss how to incorporate option-like thinking into IT project evaluation and management.

I contribute next with an in-depth field study that investigates how the confluence of two contingencies—the modularity of the infrastructure architecture and the uncertainty about whether the option will get into the money—influences developers’ choices to safeguard options.

IV. METHODS

The logic of this study is theory building from case study research [12], [55]. I draw from theoretical constructs in real options and product design to guide data collection and make sense of the empirical findings. The units of analysis are decisions to safeguard options across different infrastructure projects. This logic was chosen after a set of exploratory interviews uncovered a “de facto,” or intuitive [22], application of real options reasoning. The qualitative approach suited to overcome: 1) the reluctance of the airport operator—British Airports Airport (BAA), a public listed company—to disclose commercial data; and 2) the lack of reliable data about the evolution of the airport and airline industries over the next 30 to 40 years.

A. Research Setting

The research setting was a £4 billion (2005 prices) capital program to add a fifth terminal (T5) to Heathrow airport for coping with projected growth in passenger demand over the next 30 to 40 years. The program encompassed a number of interrelated projects for implementing corporate strategy and change. BAA developed a first version of the brief in the early 1990s, and submitted a planning application in 1995. The program scope included up to four terminal buildings (~£1.6b), the airfield (~£0.9b), a baggage handling system (~£270m), an interterminal passenger train (~£300m), and a car park (~£90m).

The airport expansion was staged over two phases (Fig. 1). The first 6-year phase originally encompassed the delivery of

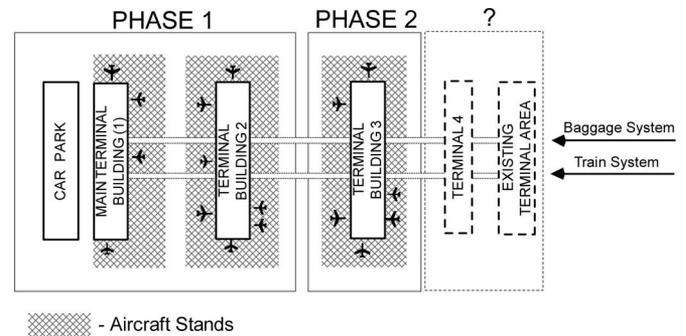


Fig. 1. Schematic layout of the Terminal 5.

two partially fitted-out terminal buildings (1 and 2) connected through the baggage handling and passenger train systems, around 40 aircraft stands, and the car park. The second 3- to 4-year phase encompassed completing the fit out for the first two terminal buildings, as well as delivering a third terminal building and the necessary extensions of the train and baggage systems. There was also a possibility to extend the train and baggage systems to a fourth terminal building and to the existing terminal area during or after the second phase.

The development process started immediately after the application was approved in 2001 with a target to open the first phase in 2008. From an organizational design perspective, BAA implemented a matrix structure. At the heart of the organization, it set up development and design teams for each major project. These “key delivery units” were supported by a top layer of functional leaders accountable for delivering program-wide processes, procedures, and management systems, and for ensuring the integration between the project teams (Fig. 2).

Each development team was responsible for identifying the respective key stakeholders (e.g., regulators, airlines, statutory authorities) and their needs, understanding foreseeable evolution in the facility and operational requirements, and publishing the facility design brief (a comprehensive register of the facilities) and the operational design brief (a description of the business strategies and operational processes). The project managers were accountable to the program board for the development, approval, and execution of the design outputs, including demonstrating compliance with the planning application documents, public inquiry conditions, and the planned budget and schedule. While the project teams had a high degree of autonomy in design decision-making, they had to assure to the program administrators that customer requirements were being appropriately addressed at monthly project boards. Project boards also provided a forum for teams to brief key stakeholders and receive advice from them, monitor progress against objectives, and approve design changes up to £2 million (2003 prices).

From the outset of the expansion program, BAA decided to build in opportunities to create business value across the projects. Opportunities could be unlocked if environmental uncertainties resolved favorably later on. Value was associated with leaving provisions to grow capacity, staging delivery over two phases, and creating flexibility to switch the

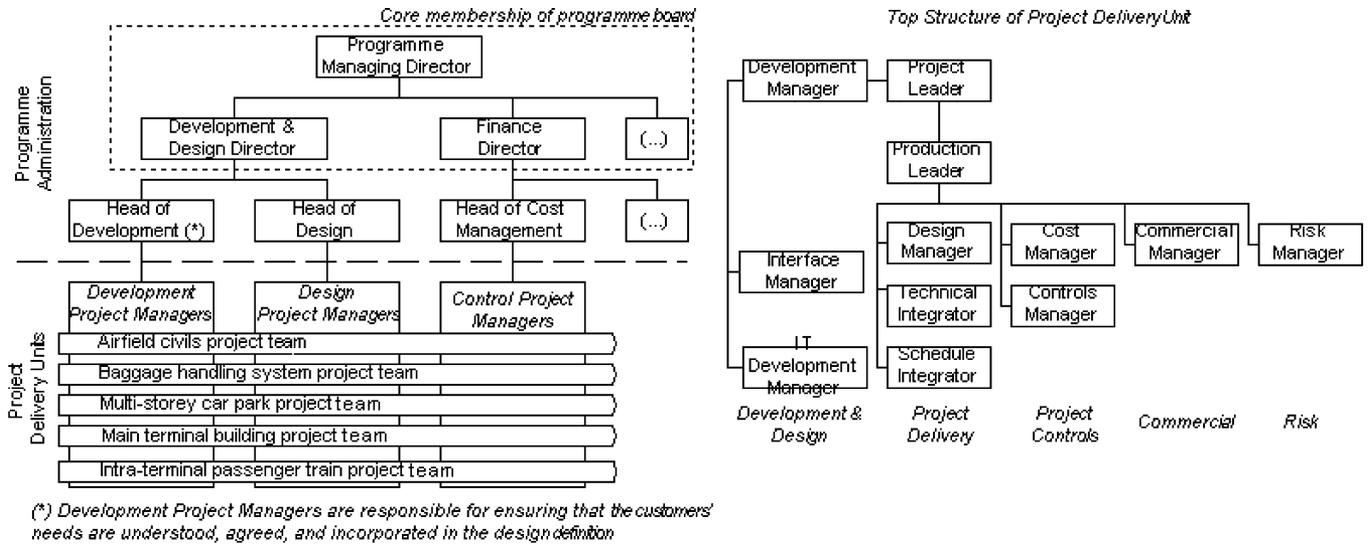


Fig. 2. Organizational structures of the T5 program and project delivery units.

operational regime. The Director of Design and Development (2005) explained this rationale:

“Do you back what you know? Do you try to speculate? Do you invest in a future that may never come? The difficulty here is that there is no right answer and different people take different approaches. Our approach is—and we are controlling it to a very tight budget—even if I can see a future now, I can only take it so far because if I try to speculate beyond any reality of today I am not going to be able to take people with me.”

BAA (simultaneously program developer and manager) did not use any option evaluation models. Yet, the program brief instructed the development teams to make discretionary investments on *safeguards* to leave open a portfolio of options. Options typically involved the substitution or addition of idiosyncratically large elements, such as a train tunnel, an aircraft stand, or a car park mezzanine. The Director of Design and Development explained:

“Safeguarding is not so much keeping my solution generically flexible. It is about saying I can see a potential future use. It is not there now, but it will be very expensive to implement it when it comes unless I do a few things now which will have limited cost. It is about *playing it safe*. The trick is about to safeguard while at the same time recognizing that *safeguarding can cost money*. So it is about how to *prudently stop waste but keep open that flexibility*.” (emphasis added)

Since each development team operated under a tight budget, the strategic option-like thinking at program level created decision-making problems at the project implementation. The more the teams spent to safeguard one option, the fewer resources they could afford to spend elsewhere in the project. I next discuss how I collected and made sense of the empirical observables.

B. Research Design

The inductive approach turned out appropriate after I uncovered the “in vivo” notion of safeguarding through open coding 15 exploratory interviews [17], [47]. A replication logic was

then followed, analogous to that used in multiple experiments, to systematically examine a sample of safeguards and accomplish a high degree of certainty on the findings [55]. A set of constructs from real options and product design were organized in empty table shells [30]. I then induced and tested the plausibility of the conceptual framework by cycling between collecting raw data and playing theory against data through tabular and graphical cross-comparisons [30]. The process stopped when theoretical saturation was reached [17].

The choice of the cases was based on theoretical sampling [12], [17], i.e., the need to build a sample representative of cases along a range of “polar types.” Thus, I examined in-depth 12 safeguards for three types of options (growth-, stage-, and switch options) across five projects: airfield, multistorey car park, baggage handling system, main terminal building, and the interterminal train system. This diversification allowed me to build a sample in which the uncertainty of option exercising and the infrastructure modularity both range from low to high extremes.

C. Data Collection

I focused the data collection process on safeguarding the options in the civil engineering systems of the infrastructures so as to develop a fine-grained database [24]. Data collection involved semistructured one-on-one interviews, analysis of over 150 secondary sources of information, such as clips in the public and trade press and project documents, as well as site observations and numerous informal conversations (Table I). I conducted 64 face-to-face interviews over more than 1-year elapsed time (from May 2004 to July 2005) by visiting the development teams in their offices at the airport site on an almost monthly basis. The visits lasted between one up to 5 days, and involved extensive preparation ahead to schedule meeting times and locations, brief the interviewees about the research questions, and clarify the nature of the study. Interviews lasted 60 to 90 min, although a few ran as long as 2.5 h.

TABLE I
SUMMARY DESCRIPTION OF THE DATABASE

Project Context	Embedded Units of Analysis		Interviews			Document Examples	Observation Examples
	Option	Safeguard	Developer	Supplier	Customer		
Airfield	O#1 Service either a code-F aircraft (wingspan up to 80m) or 2-small aircrafts using the same aircraft stand	<i>Active</i> Physically deliver 4 Multi Aircraft Ramp System (MARS) to service either one Airbus A380 or two small aircrafts	6	3		Master plan layout, operational and functional briefs, high-level programme, progress videos, press clips on terminal expansion work, design standards	Site tours, customer and supplier presentations
	O#2 Service a greater number of code-F and code-G aircrafts (wingspan up to 85m)	<i>Active</i> Physically deliver 8 aircraft stands with pavement geometries allowing to park code-F aircrafts, and 2 stands with pavement geometries allowing to park code-G aircrafts					
	O#3 Exploit lift of current restriction set by the regulator on the use of north runway due to environmental issues	<i>Passive</i> Secure space in terminal master plan for 2 taxiways connecting the new terminal campus to the north runway					
Inter-terminal Train System	O#4 Rule out passengers from taking shopping trolleys in the inter-terminal train	<i>Active</i> Physically deliver a pit in the concrete base of the train platform for installing an automatic trolley ramp	4	3	1	Project briefs, high-level programme, design drawings & specifications	Site visit
	O#5 Extend the train system to a third terminal building	<i>Active</i> Physically deliver a tunnel linking terminals 2 and 3 and an offline maintenance platform at terminal 3					
	O#6 Extend the train system to a fourth terminal building and beyond	<i>Passive</i> Secure space alignments in the airport master plan to extend the train tunnel accordingly					
Baggage Handling System	O#7 Grow throughput capacity of the baggage reclaim facility	<i>Active</i> Physically deliver space in the baggage reclaim area to install two extra baggage reclaim carrousel	6	3	2	Project briefs, high-level programme, drawings & specifications, progress video, design standards	Site visit, customer and supplier presentations
	O#8 Grow capacity of the baggage storage room.	<i>Active</i> Physically deliver a buffer area in the baggage store room for storing ~1,000 additional bags					
Multi-Storey Car Park	O#9 Increase capacity of the multi-storey car park	<i>Active</i> Engineer the concrete structure of the car park to receive a steel mezzanine to park 500 cars	3	3	1	Project briefs, high-level programme, drawings & specifications, design standards, public inquiry	Site visits
	O#10 Add a third trolley lift	<i>Active</i> Construct a pit lift and knock-out panel slabs along the future lift shaft					
Main Terminal Building	O#11 Accommodate increase in passenger throughput capacity	<i>Active</i> Build floor plate capacity for the ultimate occupancy scenario	10	8	6	Project briefs, high-level programme, design drawings & specifications, progress video	Site visits, customer and supplier presentations, supplier shop visit
	O#12 Expand area of the lounges for Commercially Important Passengers (CIP) and retail shops	<i>Active</i> Engineer the terminal building superstructure and foundations to receive steel mezzanines					

I handled the issue of internal validity by triangulating interview data across three groups of respondents: project developer (BAA), suppliers, and customers. Developer representatives (e.g., project and production leaders, development and design managers, program administrators) informed on the *raison-d'être* for embedding the options. Project suppliers (design consultants, specialized contractors, and product manufacturers) provided technical information about the safeguards. Customers (e.g., representatives of British Airways (BA)—the main customer airline, baggage operating division, and BAA retail division) complemented the information about uncertainty provided by BAA. I discussed each safeguard with at least five professionals, including an administrator, the project leader, the design and development managers, a design consultant, and a customer representative. The rigorous data collection protocol

involved tape-recording and transcribing the interviews, organizing the transcripts into a database, developing in-depth case stories, and discussing the stories with respondents to collect more data and verify the accuracy.

I addressed the problem of reliability by cross-checking interview data against onsite observations and analysis of archival documents. During the stays onsite, I examined documents posted on the intranet, including the public inquiry conditions, functional and operational briefs, design standards developed by BAA, and relevant regulation and bylaws in the airport engineering environment. To further characterize the environmental uncertainties, I gathered clips from newspapers, press releases, technical articles, and corporate reports. Occasionally, I joined ongoing activities such as supplier and customer presentations, site tours, internal meetings, and onsite work inductions.

TABLE II
SUMMARY OF DATABASE ON FORESEEABLE ENVIRONMENTAL UNCERTAINTIES

Project	Sources	Environmental Uncertainties		
		Degree of Uncertainty	Impact to the Infrastructure Design	Exemplar
Airfield	Configuration of Aircraft Fleets	High Airlines rarely disclose procurement plans for aircrafts, and the plans change over time	High Assumptions in the air fleet configurations are input to size the terminal aircraft stands and taxiways.	"We have uncertainty around the interface with the airlines because they work on a much shorter look ahead, 5-years at most" (Design Manager for Airfield 2005)
	Air Traffic Regulation	High Lift on restrictions on usage of runway contingent to evolution in inter/national policies, environmentalists' lobbying, overall economy, and environmental impacts caused by aircraft technology	Moderate Greater use of runways requires more taxiways to improve efficiency, but design of runways does not need to change	"While it would be ideal to use both runways in the same way, I just don't know when the regulator will lift restrictions on the usage of the north runway" (Airfield Designer 2005)
Inter-terminal Train	Air Traffic Demand	Moderate Projections of air traffic unanimously suggest strong growth in demand, but forecasts on exact growth rate keep changing	Moderate Ultimate design capacity is stable, but changes in the rate of growth affect the capacity needed for the first stage of the programme	"Other than STO (§) and Consolidation (†), I have not seen a lot of change...even with these two, it was more platform, more vehicles, more of something we were already providing" (Train Designer 2005)
Baggage Handling System	Air Traffic Demand	Moderate Independent projections of air traffic unanimously suggest growth in demand, but forecasts on exact growth rate keep changing	Moderate Ultimate design capacity is stable, but changes in the rate of growth affect the design capacity for first stage of the programme	"Quite a lot of uncertainty exists on user needs but it tends to lay in volumes and throughput not functionality. The big changes [STO and Consolidation] did not affect us much" (Project Leader 2004)
Multi-storey Car Park	Car Parking Demand	Low Demand for car parking space is always likely to exceed the maximum capacity for parking set by the public inquiry	High Changes in user demand would affect design capacity, which in turn would require changes to the physical structure	"The design requirements set up by the programme brief were clear from the beginning, and the maximum car park capacity was set up by the public inquiry" (Design Manager for Landside 05)
Main Terminal Building	Business Position of Main Customer Airline	High Rise of low-cost carriers, self-service check-in, rises in fuel prices, and corporate finance issues make it hard to predict how the strategic position of the airline will evolve	High Business position informs the design requirements for the passenger lounges, check-in areas, availability of jetty stands, etc.	"It has always been known that the main customer airline would like to put all its traffic into one terminal. The acceptability of it being split varies in time" (Head of Development 2005)
	Retail Strategy of Airport Operator	High Hard to predict evolution of retail market trends in the world of airports	High Changes in the retail strategy impact design of floor arrangement layouts and utility consumptions	"In the world of retail, anything more than 3, 4 years out is strategy, therefore we can never be too rigid in terms of how we are going to use the space" (Retail Director 2005)

(§) STO stands for single terminal occupancy. It refers to a 2002–2003 decision in which BAA and British Airways airline agreed to concentrate the airline operations in the new campus after the first phase, rather than leaving operations spread across multiple campuses until completion of the second phase as planned initially.

(†) Consolidation: Defined as a "value engineering exercise on top of STO," it was a major change in which BAA decided to consolidate as many operations as possible in the main terminal building, such as retail functions, while reducing the amount of floor area to deliver inside the terminal building 2.

Tables II–IV include exemplars of data, and serve as the basis for the discussion in the next sections.

V. DATA ANALYSIS

I start the analysis of the database with a characterization of the foreseeable environmental uncertainties affecting the five infrastructure projects (summarized in Table II). I then examine the assumed uncertainty of option exercising and the infrastructure design architecture.

A. Developing Infrastructure Projects Under Environmental Uncertainties

I systematically observed that the development processes for the infrastructure projects that interfaced closely with the airline industry unfolded under high uncertainty. Uncertainty stemmed from the continuous evolution in air products and services endemic to the airline industry [31]. Airlines must be constantly

adapting to volatility in the growth rates of passenger demand and in the positioning of competitors, as well as to developments in aircraft technology and new regulatory regimes. High uncertainty made it difficult for developers to assign probability estimates to the future states of the world, i.e., it created ambiguity [21]. The Design Manager for Airfield (2005) commented on the extent uncertainty impacted the design of the aircraft stands and taxiways: "It is very difficult to predict what you are going to need in 5 years from an airfield perspective because airlines change modes of operation very quickly. This is a very fluid environment, and airports have to be a responsive organization to keep airlines happy."

Likewise, uncertainty was high during development of the main terminal building. The design requirements needed to change to accommodate evolution in the business needs of the tenants, such as the airlines, the airport retail division, and the immigration authority. Developers foresaw new trends approaching, e.g., growth of onsite and online self-service

TABLE III
SUMMARY OF THE DATABASE ON EMBEDDED OPTIONS

Option Type	Option Description	(Assumed) Uncertainty of Option Exercising		Modularity of the Infrastructure Design	
		in 6-year delivery	in 20-30 years operation	Function mapping	Interfaces
Stage Option	O#7 Grow throughput capacity of the baggage reclaim area	Low "Growth of the baggage throughput capacity will be staged over two phases" (Baggage design brief 2001)	Low "The additional baggage reclaim belts are vital to accommodate growth in stage 2" (Baggage design brief 2001)	One-to-one mapping between baggage reclaiming function and modular baggage reclaiming belts	Few, standard physical interfaces between modular reclaim belts and the building systems
	O#11 Increase throughput capacity of the main terminal building	Low "There is no need for more than 80% of the floor plate area in the first phase" (Buildings design brief 2001)	Low "The development of phase 2 assumes 100% occupancy of the floor area" (Buildings design brief 2001)	Many-to-one mapping between high number of functions (retail, check-in, seating, etc.) allocated to the building floor plates	Tightly coupled physical interfaces between the building footprint and the layout of the aircraft stands
	O#5 Extend train system to a third terminal building	Scenario ruled out "The delivery of the third terminal building is excluded from the first phase" (Train design brief 2001)	Low "Forecasts support phase 2, and consequently the train extension to the terminal 3" (Train design brief 2001)	One-to-one mapping between transportation function and physical tunnel	Tightly coupled physical interfaces between train tunnel, airfield pavement, and terminal buildings
Growth Option	O#2 Service a greater number of code-F and code-G aircrafts (wingspan up to 85m)	Scenario ruled out "Large aircrafts cost a lot of money and they [airlines] don't purchase them on a whim" (Design Manager for Airfield 2005)	Moderate "It was a crystal ball predicting fleet configurations, but we could see more code-F coming...code-G is still a long way off" (Design Manager for Airfield 2005)	Limited number of functions (waiting, servicing) allocated to an aircraft stand	Tightly coupled physical interfaces between (1) the adjacent stands with one another, and (2) stands with terminal buildings
	O#6 Extend train system to terminal 4 and beyond	Scenario ruled out "We excluded the delivery of the fourth terminal from the first phase" (Design Manager for Train 2005)	High "It is a lovely aspiration but there is no sense of when it may occur" (Train Designer 2005)	One-to-one mapping between transport function and physical tunnel	Tightly coupled physical interfaces between train tunnel, airfield pavements, and terminal buildings
	O#9 Increase capacity of the multi-storey car park	Scenario ruled out "The increase of the car park capacity through addition of a mezzanine will not happen before 2008" (Car park design brief 2005)	Moderate "We are not sure if we are going to ever built it [the mezzanine] but it was a prudent decision to safeguard" (Design Manager for Car Park 2005)	One-to-one mapping between parking function and the steel mezzanine plate	Few interfaces between the steel mezzanine with the concrete structure, but high integration costs due to disruption to service.
	O#12 Expand lounges for the Commercially Important Passengers (CIP) and retail shops	Low "There is no business need to expand floor areas before the main terminal opens" (Buildings design brief 2001)	Low [Retail]; moderate [CIP]; "Someone will stick more shops about 5-10 years after the terminal opens...I'm less sure about the CIP mezzanine" (Development Manager 2005)	One-to-one mapping between lounge function and steel mezzanine plate	Few, but unstable physical interfaces between the mezzanine with the building steel structure (the geometry of the mezzanines had not yet been agreed)
	O#8 Grow the capacity of the baggage storage room.	Moderate "We do not know yet what bag-storing services we want to offer in the future" (Rep of Baggage Operating Division 2005)	Moderate "The airlines may want to use it [the spare capacity] later to offer new ticket functionalities" (Rep of Baggage Operating Division 2005)	One-to-one mapping between baggage storing function and baggage room space	Moderately coupled physical between bag handling cranes and building systems but high integration costs as huge size of the cranes makes it risky to delay installation
Switch Option	O#1 Service a code-F aircraft (wingspan up to 80m) or 2-small aircrafts using same stand	Low "We need them [large stands] to receive the A380 test flights already in 2006" (Design Manager for Airfield 2005)	Low "Based on our current flight schedule, we foresee a very good use of the asset" (Design Manager for Airfield 2005)	Limited number of functions (waiting, servicing) allocated to an aircraft stand	Tightly coupled physical interfaces between the concrete pavement with underground tunnels for M&E services, fuel, and bags
	O#3 Exploit lift of usage restriction on north runway	Scenario ruled out "It is not going to happen in the next 4,5 years" (Development Manager 2005)	High "We would like to optimize use of runway, but it may only come in 5-10 years time after 2008" (Development Manager 2005)	One-to-one mapping between airplane taxiing function and taxiway element	Taxiways have few, standard, physical interfaces with the rest of the airfield, provided that space is available in the master plan
	O#4 Prohibit passengers from taking shopping trolleys in the train	Low "The planned operating regime is unlikely to change before the terminal opens." (Head of Design for Train 2005)	Moderate "It is hard to pinpoint plausibility of Health and Safety Inspectorate's concerns" (Project Leader for Baggage 2005)	One-to-one mapping between transport function and ramp for shopping trolleys	Trolley ramps show few, standard physical interfaces with the terminal building systems
	O#10 Add a third trolley lift in the car park	Low "We are fairly certain that two trolley lifts will work" (Head of Design for Train 2005)	Moderate "Although on paper it looks right, given this scheme is new and critical, it was probably sensible to safeguard"	One-to-one mapping between transport function and trolley lift	Trolley lifts show few, standard physical interfaces with the car park building systems

TABLE IV
SUMMARY OF THE DATABASE ON THE INVESTMENTS TO SAFEGUARD THE CIVIL SYSTEMS

Option	Safeguard	Development Effort	Investment [2005 prices]	Option Exercising Costs [2005 prices]	
				w/ safeguards	w/o safeguards
1	Active Build 4 MARS to service one A380 or two small aircrafts	MARS stands have a 55cm-deep concrete central lane, which thins to 40cm	Low ~ £1.0 mil ~ 0.5% increase in the airfield civil budget	No extra investment The central lane is designed for receiving the loads of the large aircrafts, and the side lanes designed for the loads of lighter aircrafts	High Reinforcing the stands would cost 3 times more in airfield conditions; removing a stand from service can cost up to £1.5mil/day if there is no spare capacity
2	Active Build 8 aircraft stand geometries to park code-F aircrafts, and 2 geometries to park Code-G aircrafts	5m-wide buffer lane between the adjacent stands, and 20m-wide lane between the stand and taxiway so stands can be converted in future	Moderate ~ £5.0 mil ~ 3% increase in the airfield civil budget	Moderate ~ £0.7-1.0 mil/stand to reinforce the pavement of the buffer areas in airside conditions	Prohibitive To rework the stand geometries would have devastating impacts to the airport operations
3	Passive Design and secure space in master plan for 2 taxiways	Master planning effort to keep the areas free from development work	Low Marginal increase in cost of design	Moderate ~ £45 million to construct 2 taxiways in airside conditions (against £15 million if work done in landside conditions)	
4	Active Build and cover pit needed for installing trolley ramp	Build pit in the concrete basement of the train platform	Low Marginal increase in the design and construction cost	Low Marginal investment to re-open pit	Moderate Excavation work would be disruptive to passengers and train operations
5	Active Build inter-terminal train tunnel, and offline maintenance base at the terminal 3 station	Double the length of the 'cut and cover' tunnel running beneath the airfield	High ~ £70-100mil ~ 100% increase in the civil budget of the train project	Low Incremental cost to convert offline maintenance platform in the terminal 2 into a ventilation pit	High The delivery of the tunnel would be technically possible, but at a massive cost
6	Passive Design and secure alignments to extend train tunnels beyond terminal 3	Master planning effort to get the right horizontal and vertical alignments	Marginal increase in design effort	High It will cost at least £600 million to construct the tunnel	
7	Active Build space in the baggage reclaim area to install two additional reclaim carousels	Add 1,000 m ² of spare capacity to the baggage reclaim area	Low ~ £0.8 mil ~ 1.5 % increase in the civil budget for baggage	No extra investment	High Reconfiguration of the areas at the arrivals level would disrupt baggage reclaim operations and increase the risk of failure
8	Active Build buffer area for storing ~ 1,000 bags	Add 500 m ² of spare capacity to baggage storage area	Low ~ £0.4 mil ~ 0.75% increase in the civil budget	No extra investment	High Reconfiguration of the areas in the basement would be very costly and with high risk of failure
9	Active Build physical interfaces to facilitate integration of a mezzanine for parking 500 cars	Reinforce the columns and foundations, and insert the steel brackets in the columns	Low ~ £0.3 mil ~ 0.4 % increase in the civil budget	Moderate ~ £2-4 mil to manufacture and install the new steel mezzanine	High Two-fold increase to dig the new foundations and build the extra columns, plus the aesthetic cost
10	Active Build physical interfaces to facilitate installation of another lift in the car park	Construct a pit in the concrete basement and knock down panel slabs along lift shaft	Low Marginal increase on the cost of the superstructure	Low Marginal increase to open up pit and shaft	Moderate Installation costs would at least duplicate to open the shaft and reinforce the structure
11	Active Build spare capacity on the floor plates of the terminal building	Construct 20% of spare capacity in the floor plate	High ~ £20 mil ~ 10% increase in the civil budget	No extra investment	High Technically possible, but with major negative impacts to the operations inside the terminal
12	Active Build physical interfaces to facilitate integration of mezzanines inside the terminal building	Conservative reinforcement of the concrete foundations and steel structure	Low ~ £0.25 mil ~ 0.1% increase in the civil budget	Moderate ~ £1-2 mil to manufacture and install the new mezzanines	Moderate Technically possible, but with major impacts to operations at the departures level

check-in, pressure to boost revenues from retail areas, and stringent security requirements. The trends would likely cause changes to the floor arrangement drawings over time, but developers could not predict the exact growth rate of these trends years ahead.

Environmental uncertainties were more moderate in the development of the baggage and train systems. The main design inputs of both transport systems consisted of: 1) forecasts of passenger and baggage throughput per year, per day, and in a 15-min peak time; and 2) operating performance criteria, such as service frequency and maximum passenger-waiting times. Changes in the design capacities were unlikely because BAA was interested in growing the business to the maximum capacity set in the public inquiry as the airport already operated above the design capacity. Further, changes in the operating criteria for the two systems needed to be incremental as the criteria were tied to corporate service standards valid across all the airports owned by BAA. However, the train and baggage systems were not required to operate at maximum capacity by the end of the first stage since by then only two terminal buildings would be in service. The exact timing of the start and completion of the works for the second stage was a chief source of uncertainty.

In contrast, environmental uncertainty was low in the car park project because, first, most design principles were crystallized in the airport operator's standard for designing car parks. And second, the design capacity was foreseen to remain stable around the maximum set by the public inquiry because parking fees accounted for almost a third of the revenues generated by the airport business. I next examine how these uncertainties influenced the developers' assumed uncertainty about whether the options would get in the money and be exercised over time.

B. Analysis of the Embedded Options

Table III describes the 12 options in terms of the uncertainty of option exercising and modularity of the infrastructure architecture. The exercising costs are discussed when examining later the safeguards. I disregard the time for the options to expire because most real options are perpetual, i.e., they stay open throughout the lifetime of the asset [3].

C. Assumed Uncertainty of Option Exercising

1) *Stage Options*: I identified a literal replication [55] on the pattern of uncertainty of option exercising for the stage options in agreement with theory: stage (or time-to-build) options exhibit less uncertainty than other options around whether and when they are likely to be exercised [50]. The assumed likelihood of exercising the stage options was systematically low during delivery of the first phase and high afterward. Projections based on 40 years of historical data consistently pointed to a 4–5% average yearly growth rate of passenger demand over the 30-year planning horizon. The observations of the Design Manager for the Train illustrate this pattern: “We have always designed the train system to support this expansion: its capacity, the size of the stations, the number of cars in the train, egress, ventilation, etc. All those sort of things were understood and accommodated in the design.” There was, however, uncertainty

on the timeframe when the stage-options would be exercised. In particular, developers did not foresee upfront that the physical delivery of the stage-options would need to be completed 3 years after completing phase 1; as put by a program administrator: “we probably wouldn't know [in 2001–02] if we would open terminal 3 in 2011, we might have said 2013 or 2015, but we knew we had to do it.”

2) *Growth Options*: There was more variability in the assumed uncertainty of exercising the growth options. The option to expand the retail area in the main terminal through addition of a mezzanine, for example, showed low uncertainty because expansions of retail areas are almost inevitable in privatized airport terminals to increase revenues and meet business targets over time. On the other hand, the option to expand the train system to terminal 4 and beyond showed high uncertainty because the business case for the expansion was unclear. In between, there were some growth options with moderate uncertainty, such as the option to increase the number of stands for servicing large aircrafts. This situation was described by the Design Manager for Airfield: “We believe in time something will happen: our demand some years ago was about 48 million, now we have moved into 60 million; 30% of flights on now are 747s, and in time we will see similar progression with A380s.” The acquisition of large aircraft remains the only alternative through which BA can meet the forecasted growth of passenger demand because Heathrow airport operates close to the regulated cap on the maximum number of flights per year. Yet, uncertainty was high about when it will happen because airlines do not disclose years in advance their purchasing plans, and the large aircraft were still under development.

3) *Switch Options*: Switch options that provided operational flexibility to accommodate hindsight learning on passenger usage, such as the options to add a new trolley lift in the car park or a trolley ramp in the train station, showed moderate uncertainty of exercising. While designers were generally convinced on the correctness of the design solutions, the lack of good models to simulate human behavior lessened their confidence on the results or at least made them controversial:

“A passenger arrives at the check-in desk with luggage on the trolley. If we provision a rack to leave the trolley, how many passengers will put it there? We do not know, so we need to leave some flexibility to run it for a while before we optimize. You can make assumptions but they may not necessarily come out correctly.” [Program Administrator 2005]

In contrast, the uncertainty of exercising was low for the option to build four aircraft stands. These stands aimed to serve either a large aircraft such as the new Airbus A380 or two small aircrafts at the same time. An Airfield Designer explained: “We felt we needed operational flexibility to change between small and large aircrafts, particularly with the aircraft stands around Terminal 2. So we decided to MARS [multi aircraft ramp system] four of them. MARS stands kind of double the amount of services you have to provide: you mark up two smaller central lines besides the main central line, you add more stand entry guidance systems, more fuel pods, more pier services, more expensive loading bridges, etc.” To reduce uncertainty

about option exercising, BAA could make the stands available to all airlines using the airport.

I examine next the architecture of the civil engineering systems of each project as a context for safeguarding.

D. Modularity of the Infrastructure Design Architecture

The analysis of the architecture of the civil engineering systems differentiates three situations: First, a functional element with a modular interaction in relation to the surrounding civil systems was available from the outset of the development process; second, the interaction of the functional element was modularized in relation to the other civil systems during development; and third, the functional element remained integral to the other civil systems because breaking apart the interdependences was unaffordable.

1) *Functional Modules Available Ex Ante of the Infrastructure Development Process:* The availability of functional elements with modular architectures at the development outset occurred with technologies that have little stand-alone value, yet they are valuable once integrated in the infrastructures that need them. The addition of single-function modules, for example, was part and parcel of installing a trolley ramp, a passenger lift, or a baggage-reclaim belt. These elements involve technologies with stable design rules specifying the interfaces with the civil systems, as the supplier director for lifts and escalators explained: “Our design process is different from other people. We have a product for more than 25 years. Our machines generally sit on the edge of the structure on a rubber pad. We just need to tell people the size and depth of the pit, the electrical power, and how the control panel interfaces with fire alarms.” The limited group of firms that supply these technologies—over 80% of the world market share for lifts and escalators belongs to 7 companies [29]—may be said to form a modular cluster in the same way clusters play host to the evolution of modular computer designs [5].

2) *Development of Functional Modules During the Infrastructure Development Process:* In a second group of cases, designers modularized the architecture of selected functional elements. The structure of the car park, for example, was designed to receive the additional load of a steel mezzanine for parking 500 cars without affecting its esthetic qualities. Likewise, some open voids were purposely created into the architecture of the main terminal building to allow for an expansion of the retail and CIP lounges through addition of modular steel mezzanines. Unlike the car park example, however, the exact shape of these mezzanines was not firmed up upfront, forcing the designers to conservatively assess the design loads of the future mezzanines.

3) *Coping With Integral Architectures Throughout the Infrastructure Development Process:* In a third group of cases, designers were unable to modularize the interaction of the functional elements with the surrounding civil systems. The design interdependences that were hard to break apart could be between the functional element and the civil systems of the same infrastructure project, or between the functional element and civil systems belonging to other infrastructure projects. The

concrete layer of the pavement of the aircraft stands (a set of layers of granular materials topped with a thick concrete layer), for example, remains integral with the tunnels carrying the mechanical, electrical, fuel, and baggage systems under the stands. The service ends of the tunnels penetrate the concrete layer of the pavement in various locations on both sides of the central lane where the aircraft wheels park. Further, aircraft stands and taxiways are designed adjacent to one another, which means a stand cannot be enlarged: 1) widthwise without reworking the adjacent stands; and 2) lengthwise without moving the central line of the taxiway adjacent to the back of the stand or without changing the width of the taxiway.

In a second example, designers were unable to find a modular design to the main terminal building that could efficiently support the strategy of staging the delivery into two phases—“normally, our way” as put by one respondent. Developers wanted to maximize the provision of aircraft stands surrounding the building footprint in the first phase. Late construction work to add a second building module, however, would put temporarily out of service a number of stands, an integration cost that BAA could not afford (emphasis added):

“We looked to all sorts of options of how to construct the main terminal building in two phases because we wanted to accommodate 20 million [passenger throughput/year] in phase 1 and 30 million in phase 2. We locked bits off, did funny configurations, but all had problems in terms of efficiency. We could not make the building layouts to work without losing stands during expansion, and *stands are always our most precious resource.*” [Head of Design and Development 2005]

Both examples corroborate theory in product design. A caveat with modularization is that designers need to set limits of the modularity they wish to achieve to avoid problem-solving in an immense space of possible designs [5] and offsetting the gains with the time spent in the testing and integration phase [13]. I next piece together the two contingencies to shed light on the attractiveness of safeguarding.

VI. DISCUSSION: FROM PASSIVE TO ACTIVE SAFEGUARDING

Table IV summarizes the investments on safeguards into the civil engineering systems for each of the options in Table III. It describes the safeguards and shows how they impact the exercising costs, and what the implications would be had the safeguards been ruled out.

I systematically observed two types of investments in passive safeguards: 1) to document foreseeable space requirements in the master plan layout; and 2) to design the structures temporarily occupying those spaces in a way they can be economically relocated, or sacrificed, in the future. Passive safeguards suited when the uncertainty that the option would get in the money was high, as put by the Director of Design and Development: “It [passive safeguarding] means that I’m not going to invest in anything now because it is too uncertain to make it worthwhile, but I’m going to make sure I have space that I can use if that comes along.” In contrast, active safeguards suited when: 1) the uncertainty that the option would get in the money was

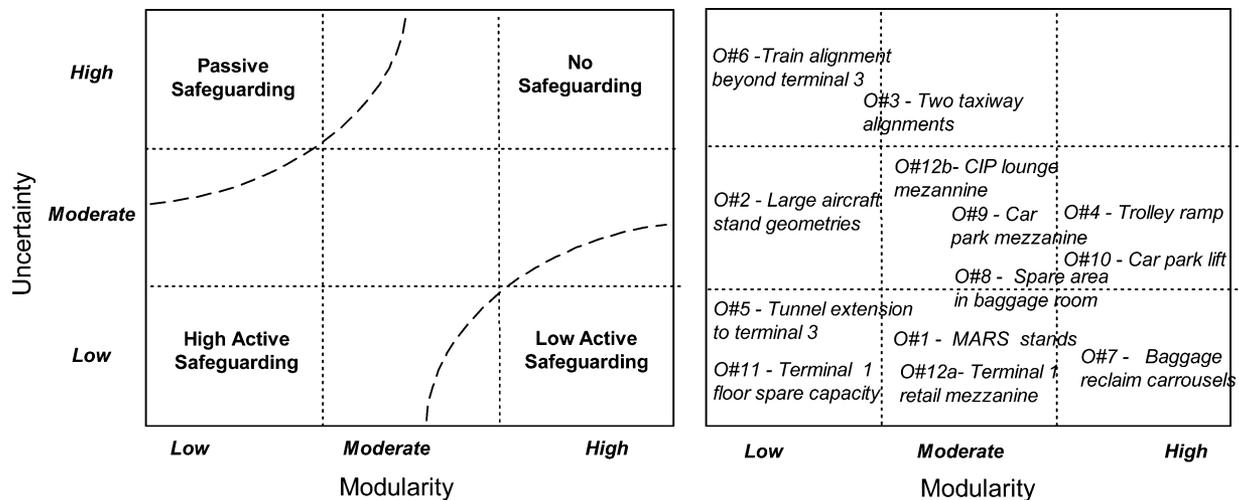


Fig. 3. Attractiveness of safeguarding according to the uncertainty of option exercising and modularity of the infrastructure architecture in theory (left) and for case data (right).

low/moderate; and 2) the exercising costs would otherwise escalate because the infrastructure was not modular:

“I call active safeguarding when we decide to make an allowance now because not doing so would be silly. It is where we specifically put money in the ground to safeguard something for the future so there needs to be a clear demonstration that it is better to build it today than to incur greater cost tomorrow, which is about investigating if there is a practical solution to build it in the future or not.” [Program Administrator 2005]

Fig. 3 (right) maps the instances of safeguards over a two-dimensional space combining the uncertainty of option exercising with the modularity of the infrastructure architecture. Fig. 3 (left) abstracts the mapping into a conceptual framework.

A. Attractiveness of Investments on Passive Safeguards

Passive safeguarding emerged attractive when the uncertainty of option exercising is high and the modularity of the infrastructure architecture is low (top left quadrant in Fig. 3). High uncertainty dissuades developers from making major irreversible commitments in the active safeguarding of integral designs. In this situation, passive safeguarding is more attractive. This was the case, for example, of securing space to expand the train tunnel beyond terminal 3, an option assumedly too far “out of the money”:

“The safeguarding was passive for expanding the train: first, a track alignment, vertically and horizontally, was safeguarded to allow a possible extension; second, the design of the maintenance facility was safeguarded to revert in the future into a running tunnel if the train is extended.” [Design and Development Manager for Train System 2005]

Likewise, passive safeguards ensured that the option to add two more taxiways stays open without investing the £15 million (5% of the civil system budget in the airfield project) otherwise necessary to build the taxiways. In this case, the exercising costs will be three times higher in the future because the work will be then undertaken in airside conditions, which involves night shifts and stringent security requirements. Assuming that un-

certainty stays high, passive safeguarding loses attractiveness as the architecture gets more modular. This suggests a situation of mutually exclusive investments [23]: why invest on safeguards at the present to enhance the embedment of an option with high uncertainty if modularity suffices to ensure that the cost of exercising that option will not escalate in the absence of safeguards?

Exercising costs can escalate when investments are made on passive safeguards if the infrastructure architecture is integral. For example, the extension of the train tunnel beyond terminal 3 was passively safeguarded. Yet, the construction of this extension in the future through the cut and cover method—the most economical method—will be prohibitive because various aircraft stands and taxiways would have to be put out of service during the works. The tunnel extension can be excavated using a boring machine, but the costs will increase at least sixfold.

B. Attractiveness of Investments on Active Safeguards

Investments on active safeguards get increasingly attractive as the uncertainty of option exercising decreases. When both the uncertainty and modularity are low (bottom left quadrant in Fig. 3), the irreversible outlays on safeguards can be very high. The airport operator, for example, invested massively to build the tunnel connecting the terminals 2 and 3 in the first phase, although the trains would shuttle back and forward between the terminals 1 and 2 until the end of the second phase. The switch of the train system into a three-station system will require its reconfiguration into a pinched loop mode by joining the two independent guideways into a loop configuration. The offline maintenance base at terminal 2 will be converted into a ventilation pit (to help remove smoke in case of an accident) and a new offline maintenance base will be installed in terminal 3, although as one respondent noted “the business case for terminal 3 can always collapse if passenger numbers drop after a major disruption.”

Assuming that uncertainty is low, active safeguarding gets more attractive with high modularity because: 1) the need to

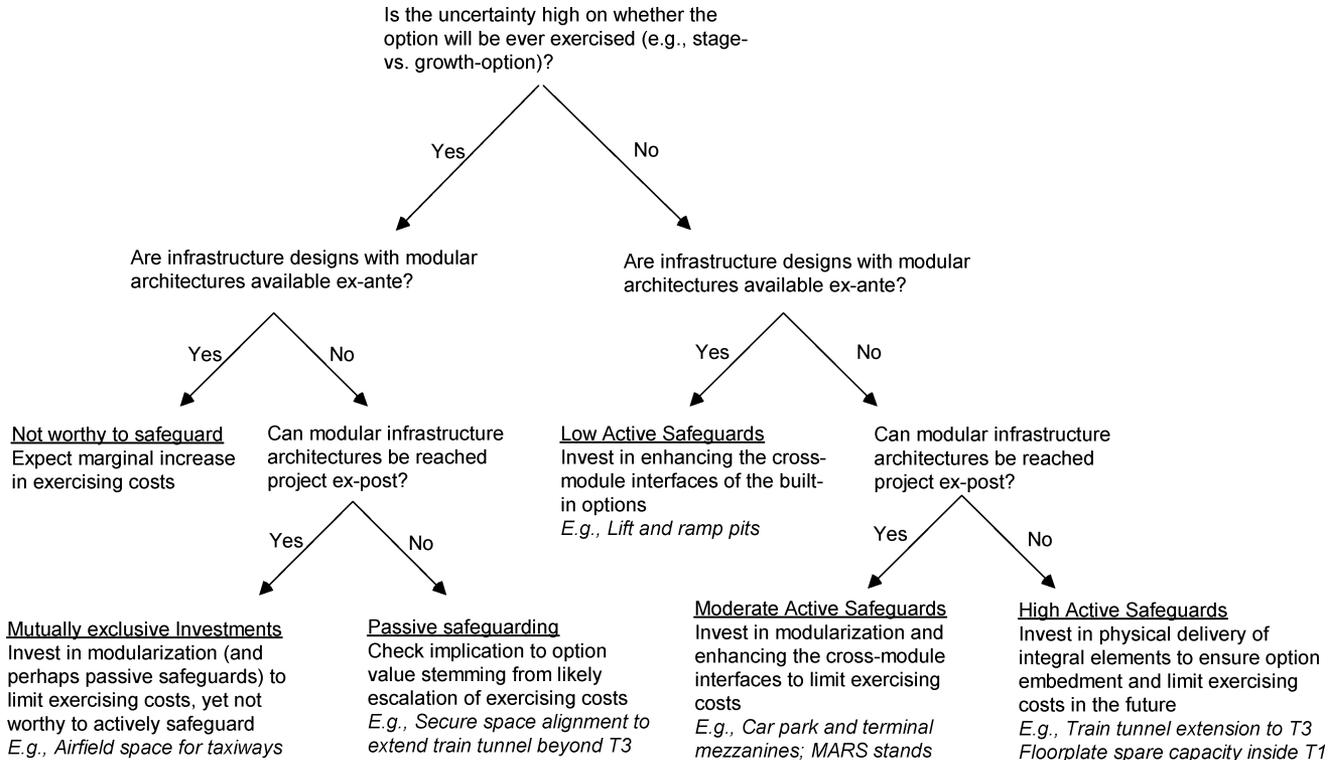


Fig. 4. Decision-making on safeguarding.

only safeguard the interfaces reduces the required outlays; and 2) the stability of the modular design rules reduces the risk that the technical assumptions lose validity over time¹ (bottom right quadrant in Fig. 3):

“You must never build something unless you have a reasonable confidence it is going to be required, and when it is required it will be of the same size, shape, or whatever. You do not want to safeguard underground buildings to discover later that it is in the wrong place when you come to use it.” [Train System Design and Development Manager 2005]

Stylized “decision trees” are useful to summarize choices between alternatives based upon a set of conceptual determinants [49]. Fig. 4 summarizes the decision-making process of safeguarding.

Firms tradeoff constantly the flexibility value from postponing irreversible investments with the commitment effect from precommitment investments to gain strategic advantage [45]. At the strategic level, competitive forces providing incentives for firms to invest early include sizing a first-mover’s advantage and preempting competitors’ actions. At the project implementation level, the empirical findings suggest that the investments on safeguarding are influenced by design modularity and the uncertainty of option exercising.

VII. LIMITATIONS AND OUTLOOK

I addressed the issues of internal validity and reliability by strictly adopting the methodological guidelines for building the-

¹In the airport environment, practitioners call it the “are you going to get it right?” question.

ory from multiple-case study research. I controlled for internal validity by sampling data across five project cases, but all cases emanate from the same capital program. This single-firm approach raises reproducibility and generalizability issues that only further studies can address [49], [55]. This article provides, however, enough details on the research protocol to enable others to reproduce it, and falsify our findings.

It is worth noting that the investigation was limited to intraprogram options, i.e., options that were valuable in and by themselves rather than being a prerequisite for subsequent expansion programs. Admittedly, I observed an instance where the airport operator invested massively to safeguard an option to connect a heavy rail line to the new terminal campus in a hypothetical subsequent expansion. This option exhibited high uncertainty of exercising, but a senior manager characterized this irreversible investment as “purchasing a license to expand and operate in a world where sustainability increasingly matters.” This suggests that an interprogram compoundness relationship [50, p. 133] can also affect safeguarding. Care must therefore be taken before applying the insights to dissimilar option-like investments.

I did not test the external validity of this work into other industrial sectors. Baldwin and Clark [5] argue, for example, that the modularity in computer and software designs has enabled the computer industry to evolve into a large cluster of modular firms with stable design rules governing the architecture and interfaces of the systems. In contrast, building systems with integral architectures abound in physical infrastructure projects, and infrastructures are inherently integral to the land they occupy. These differences, arguably, did not preclude program administrators

from spelling out needs to safeguard the development of the baggage handling control systems, which the senior systems architect interpreted as follows (emphasis added): “There are several IT systems that they [BAA] know could potentially be integrated if they identify a real business case. *All we did to passively safeguard* was to provide some “hooks”: we found out what type of info is required, how fast they want it, how much, how frequently, and prepared the right data structures to help people go back in there one day without causing problems, *but we would only perform coding in active safeguarding.*” Clearly, more in-depth studies are needed to investigate how our findings can translate into the world of digital projects.

There are some other related areas that the study does not address, but merit further attention. First, it remains indeterminate the optimum level of investment on safeguards where a marginal increase on investment may equate the marginal benefit for the option value. This issue can be investigated through analytical models. Second, the study examines the impacts of safeguarding to option exercising costs against the budget of one engineering system. A comprehensive study that analyzes all the systems affected by an investment in safeguarding can yield other insights that this work may have overlooked.

Finally, the study is based upon the assumed uncertainties of option exercising, which were elicited by cross-checking design briefs against retrospective inquiry. Perceptions on uncertainties and the availability of the wherewithal to fund option exercising change over time, however, as new people come and unpredicted events take place. These changes over time instill, understandably, reluctance on developers working with tight budgets to safeguard the options exhibiting high uncertainty; as put by a Project Leader: “Generally, we accept rework. There are many examples in this airport where people had good ideas and buried something in the ground for future possibilities that never happened. If you can predict the future, then you can safeguard but in this sort of world you will not get lucky regularly.” To the extent developers could make more reliable assessments on uncertainty, their choices on safeguarding would likely change. Research and practice, for example, advocate combining the options approach with scenario planning (e.g., [2], [10], [33], [36]). Scenarios consist of a number of alternative plausible stories regarding the longer term future of the external environment [42]. Strategists can also help developers build a more informed understanding on the likelihood of uncertainties resolving favorably in the future and the value of strategic adaptability under uncertainty (e.g., [18]). It merits intersecting the findings here with work on scenario planning and design of project organizations.

VIII. IMPLICATIONS TO THEORY AND PRACTICE

In a real-world environment of competitive responses and volatile markets, strategists are exhorted to employ option-like thinking for informing strategic investments on infrastructure. This trend is likely to grow as governments increasingly resort to private investment to fund and operate new infrastructures [34]. Smit [44], for example, shows how European markets appreciate the growth opportunities of publicly traded airports, where the

value of a growth option as a proportion of the stock price can range between 40% to 50%. The framework here yields a way of thinking about how the confluence of two determinants influences safeguarding. Its competent use can be turned into a managerial skill for developers.

This study also sheds light on the role of safeguarding as a complement of modularizing. Properly used, both methods can ensure that the new structure can cope efficiently with changes in design requirements. When uncertainties resolve favorably earlier than planned, the developer may need to exercise an option during project delivery. The exercise of the stage options in this study, for instance, was anticipated almost 3 years. BA and BAA agreed to change the planned operating regime in the face of, among other factors, high rates of growth in passenger demand and surge in competition. The safeguarding of the stage options moderated the impacts caused by the disruption of exercising them prematurely. This could otherwise have led—speculatively, I admit—to a project failure. Once the infrastructure is operating, safeguarding contributes to operationalize Simon’s [43] principle that developers should “avoid designs that create irreversible commitments for future generations.”

These findings also have implications for theory. The scarcity of studies on applications of real options has motivated calls for empirical studies (e.g., [1], [27]). The dearth of field studies on implementing corporate strategy at the project level has also been noted (e.g., [35]). The results uncover an important two-way relationship between strategic option evaluation and project implementation. An underinvestment on safeguards can devalue good options that otherwise could create value for the firm. Yet, the more developers perceive murkier and far away option exercising—two factors that increase the value of the options—the less interested they are in safeguarding. These findings resonate with recent work intersecting options theory with other lenses, sometimes with results contrary to standard option analysis (e.g., [19], [45]). The intersection of options and game theories, for example, has shown recently that the option value may be eroded rather than increase monotonically with uncertainty when competitive forces provide incentives to invest early [45], p. 322]. Our findings suggest that option evaluation may need to factor in the footprints left by option-like thinking at design implementation since the latter influence both the option cost and the option value.

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