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Project risk management and design flexibility: Analysing a case and conditions of complementarity

Nuno Gil[a,*], Bruce S. Tether[b]

[a] Centre for Infrastructure Development, Manchester Business School, United Kingdom
[b] Imperial College Business School, United Kingdom

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ABSTRACT

We explore how risk management and design flexibility interplay in major (infrastructure) projects, using the £4.2bn Terminal 5 project to expand London's Heathrow airport. By juxtaposing these two conceptual frames, we unearth the conditions under which they can be complements for managing the tension between efficiency and effectiveness central to these projects. Building design flexibility – through modular or safeguarded integral architectures – increases adaptability to accommodate evolving requirements which is necessary to attain effectiveness. Efficiency, in turn, demands risk management to deliver the project 'on time, within budget'. We explain variation in the interplay between the two approaches, highlighting the moderating role of the developer's relationship with the customer. Strong co-operation, particularly in a stable environment, encourages investments in design flexibility. Risk management practices prevail when co-operation breaks down. Another insight is that co-location and continuity of key project staff are themselves inadequate conditions to sustain co-operation.

1. Introduction

Large-scale infrastructure assets such as an airport terminal, power station, or high-speed rail line are delivered through one-off, multi-year, capital- and engineering-intensive projects. The symbiotic relationship between the developer, who incurs the capital costs, and the customer(s) who will operate the asset, is central to these projects. Because customers' needs evolve over time, they understandably want process flexibility to postpone design decisions and request late changes. But keeping the design fluid during physical execution is challenging, as gains in the effectiveness of the final asset may come at the cost of lost efficiency in project delivery, increasing the time and/or cost required for project completion. Hence, this tension between efficiency and effectiveness is a key characteristic of large infrastructure projects, and of large engineering (major) projects more generally (Morris, forthcoming).

The risk management literature applied to major projects has recognised this tension. Scholars recognise that adapting the project to changes in customer needs can be business critical (Dvir and Lechler, 2004; Gil et al., 2006; Miller and Lessard, 2000). To decide whether to accede to a customer's re-design request, project teams are urged to appraise and manage the risks of adapting the elements that are under detailed design or construction, as well as those elements that have been completed (Cleland and King, 1983; Cooper and Chapman, 1987; Morris and Hough, 1987). Changes are typically accepted when their prospective benefits to future operations are thought to outweigh the adaptation costs and risk of delays, which can both be significant, especially in projects with integral design architectures (Shenhar, 2001; Floricel and Miller, 2001).

Extraordinarily, however, the development of project risk management has barely intersected with studies on commercial new product development, which consider the comparable problem of achieving efficiency whilst attaining consumer satisfaction. In this world, scholars advocate the use of modular architectures to achieve flexibility and substitute risk management under uncertainty (Thomke, 1997). Modularity enables set-based design and mass customisation practices, both of which permit a range of final products to be offered to consumers within the scope of the flexibility deliberately built into the architecture (Pine II, 1993; Sanchez, 1995; Sobek II et al., 1999; Clark and Fujimoto, 1991; Ward et al., 1995; Feitzinger and Lee, 1997; Iansiti, 1995). Design modularity also enables developers to exploit product platforms over their lifecycle (Sanderson and Uzumeri, 1995; Martin and Ishii, 2002) and to postpone design freeze to incorporate cutting-edge technologies for which premium prices can be charged (Iansiti, 1995).

To explore how risk management and product design flexibility interplay in major projects, we undertook an inductive, multiple-case study of the £4.2bn (in 2005 prices) Terminal 5 (T5) project to

* Corresponding author.
E-mail addresses: nuno.gil@mbs.ac.uk (N. Gil), b.tether@imperial.ac.uk (B.S. Tether).

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expand London's Heathrow airport. Designed to handle 35 million passengers per year, BAA, the private owner–operator of Heathrow airport, began planning T5 around 1989. Planning consent was granted in 2001, and schematic design and construction began concurrently in September 2002. T5 opened 'on time and within budget' in March 2008. Our research design focuses on a key unit of analysis: co-design processes. We examined co-design processes for selected functional elements across different subprojects that involved the BAA's T5 team (the 'developer') and three separate future operators, the project customers.

Our key contribution is a theoretical, longitudinal understanding of the conditions under which risk management and design flexibility can complement each other for managing the tension between efficiency and effectiveness in major projects. Critically, we find that the developer's willingness to invest in design flexibility – through modular or safeguarded integral architectures – is moderated by the extent the developer and customer co-operate effectively during the project. Effective co-operation encourages investments in design flexibility, whereas poor inter-relations encourage the realisation of a more rigid architecture. The lack of product flexibility increases the costs and risks of adapting the design to accommodate evolution in customer needs, shifting the emphasis toward project risk management. Interestingly, we show co-location and continuity of key project personnel are insufficient conditions to achieve and sustain effective cooperation.

2. Background: project risk management and design flexibility

That performance is related to both achieving specified goals on time and within budget, as well as meeting customer requirements, is a notion central to both the management of major projects and to commercial new product development. In these two worlds, however, two largely separate frames have developed as to how to manage the design process: risk management and design flexibility. Risk management, particularly in relation to budget and schedule overruns, is central to the literature on the management of major projects. It is also fundamental to 'best practice', as championed by the professional project management institutions (PMI, 2004). In these projects, risks are influenced by three main factors (Morris, forthcoming).

First, is the importance of 'front-end strategizing'. This notion exhorts developers to invest time and effort at the project outset thinking through alternative scenarios that might affect design requirements. Seminal studies on managing risk stress the importance of prescriptive activities including defining the project scope and tasks; identifying risks, their likelihood and potential impacts; and planning contingent actions and budgets to counter impacts (Cleland and King, 1983; Cooper and Chapman, 1987). Scholars have also advocated combining prescriptive tasks with other up-front activities, such as scenario planning, options reasoning, talking to end-users/communities, and discussing the politico-economic environment with key project stakeholders (Morris and Hough, 1987; Morris, 1994; Miller and Lessard, 2000). Front-end strategizing aims to reduce the occurrence of 'strategic surprises' (Floricel and Miller, 2001) and 'goal changes' (Dvir and Lechler, 2004), but it cannot eliminate uncertainty in design requirements during the project's lifecycle.

Second, is the inevitability of unforeseen – and often unforeseeable – events occurring and affecting the project, regardless of the effort invested in front-end strategizing. To mitigate the risks arising from late adaptation, especially when many design variables interact, project teams are urged to build capacity to re-plan through test-driven iteration, 3-D modeling and rapid prototyping, and to pursue multiple solutions concurrently (De Meyer et al., 2002; Sommer and Loch, 2004). Scholars also exhort developers to invest in relational forms of contracting with suppliers, as these commercial arrangements encourage co-operative behaviour that translates into commitment, shared goals, and flexibility to cope with late changes in design requirements (Stinchcombe and Heimer, 1985; Clegg et al., 2002; Gil, 2009; Henisz and Levitt, 2009).

Finally, is the need to manage customers' behaviour and expectations. Customers can unnecessarily disrupt project execution by insisting on design changes, particularly when these are made late, and/or could have been foreseen and therefore incorporated into the design earlier (Shapiro and Lorenz, 2000). Customers often violate the project process without fully realising the implications of their behaviour for the project's progress and budget (Genus, 1997; Geyer and Davies, 2000). Aware of these issues, Hobday (2000) suggests that project administrators' needs should outweigh the influence of functional managers and customer directors. Others recommend setting up governance structures that make explicit the cost of late design changes (Ross and Staw, 1986; Miller and Lessard, 2007). Clegg et al. (2002), meanwhile, advocate an 'alliance culture' fostered by frequent meetings with the customers to discuss how to accomplish a 'future perfect' outcome when 'planning is almost impossible'. This approach brings soft skills such as communication, emotional intelligence, leadership, and motivation to the fore (cf. Morris and Pinto, 2004; Doherty, 2008).

All of these practices concern managing project risks, rather than deliberately building product flexibility into the schematic design. In marked contrast, building flexibility into the product design through the use of modular architectures is central to the approach often used to reconcile efficiency and effectiveness in commercial new product development (Clark and Fujimoto, 1991; Sanderson and Uzumeri, 1995; Ulrich and Eppinger, 1995; Ward et al., 1995; Feitzinger and Lee, 1997; Thomke and Fujimoto, 2000). Here, close attention is paid to the product architecture, which is the 'scheme by which the function of a product is allocated to physical components' (Ulrich, 1995). Integral architectures exhibit complex mappings and tightly coupled interfaces between components. Modular architectures, by contrast, relate to Simon's (1962) concept of 'nearly decomposable systems'. They break apart complex systems into an array of functional components and a set of design rules that de-couple and standardize the interfaces between the components (Ulrich and Eppinger, 1995). Because modules may be multi-functional, Baldwin and Clark (2000) rather define modules on the basis of relationships, i.e., units whose structural elements are powerfully connected amongst themselves and relatively weakly connected to elements in other units. Modularity increases the possibility space for final designs provided these conform to the rules and integration protocols agreed upfront (Baldwin and Clark, 2000). Overall, when design flexibility is high, the cost and time required to keep the design fluid until close to market launch is low because one module can be modified with little or no impact on others (Thomke, 1997).

Product modularity is neither free nor easy to achieve, however (Baldwin and Clark, 2000, 2006; Whitney, 2004). In the absence of modularity, more limited flexibility can be incorporated through the use of 'safeguards' or buffers (Gil, 2007, 2009a), such as over-engineered foundations and conservative equipment choices, built into integral architectures. These design allowances aim to limit or suppress the ripple effects of foreseeable changes to one element to other interdependent elements, and accordingly, limit the costs of exercising the built-in options in a possible future. Yet, safeguarded architectures are also more expensive than those without built-in flexibility. Despite occasional calls for postponing design decisions (Gil et al., 2006) and for developing major projects in self-standing modules (Morris, 1994), empirical studies of how design flexibility is incorporated into major projects are very scarce. Anecdotal evidence suggest developers are interested in achieving flexible architectures, e.g., high-rises and car parks that can later accommodate additional floors, or factories that can be tooled by quadrants as demand materialises (de Neufville and Scholtes, forthcoming; Gil et al., 2005). Both risk management and design flexibility are therefore relevant to the development of major projects. Yet, how design flexibility is incorporated, and how it interplays with risk management remain barely explored questions. It was to investigate these questions that we undertook this in-depth study of the T5 project.

3. Methods

3.1. Research design and setting

Ours is an inductive study with units of analysis embedded across multiple cases (Yin, 1984). The empirical setting is the T5 project, which is attractive because BAA made the project a test-bed for new managerial ideas. From the outset, BAA's top management was concerned that major projects often experienced substantial budget and schedule overruns, with fractious relationships between stakeholders. BAA even forecasted that, if undertaken in the same way as other major projects in the UK, T5 would open 2 years late and cost up to £2bn more than budgeted (BAA, 2004). A failure of such proportions may well have ruined the company, the market capitalisation of which was less than £5bn in 2005. Seeking to avoid this, and influenced by an industry-government report entitled *Rethinking Construction* (1998) chaired by Sir John Egan (BAA CEO from 1990 to 1999), BAA determined to do things differently. They imported tried and tested ideas – such as design postponement – from the automotive industry, within which Egan had built his career. These ideas were new to the world of major projects, however. Alongside this, and mindful that late changes bedevil major projects, BAA invested heavily in risk management best practice, including a governance structure, front-end strategizing, risk registers, and prototyping. In 2003 the company announced that T5 would be built 'within budget' and open in March 2008, constructing the risk that T5 might not be open on day one.

This study uses a comparative case approach, with the cases working as experiments in replication logic, enabling us to develop, test, and ground the conceptual insights (Yin, 1984; Eisenhardt, 1989). The innovative managerial ethos of the T5 project provides a shared context to the study. To create a diverse sample, we investigated different interactions between the BAA's 'T5 team' – the business unit set up and led by BAA to design and manage the project – with three customers: 1. BAA Retail (hereafter Retail), an 'internal' customer, and the organisation responsible for managing the concessionaries at BAA's airports; 2. British Airways (BA), an 'external' customer, and the airline that would operate from T5; and 3. National Air Traffic Services (NATS), another external customer, and a public–private partnership that provides air traffic control services at Heathrow airport. The T5 team had limited production capabilities; it was really a 'systems integrator' (Hobday et al., 2005; Davies et al., 2009), being in charge of capturing customer requirements, and selecting and managing the supply chain capabilities.

3.2. Data collection and coding

The data collection and coding process was informed by our central research question (Eisenhardt, 1989): How do risk management and design flexibility interplay in major projects? To explore this question, we embedded units of analysis that relate to the co-design processes for selected large functional elements: the retail and check-in spaces in the main concourse; the air traffic control room in the control tower; and the layout of the aircraft stands. Common to these was a high degree of customer involvement in design under conditions of uncertainty. The units were sampled to deliberately vary the extent of the flexibility which was ultimately incorporated into the design architectures, and the corresponding balance between the use of product flexibility and risk management. Table 1 provides a summary description of the units of analysis (Table 1).

Table 1
Description of cases and units of analysis.

Case: developer–customer interaction	Unit of analysis: co-design process for a large-scale functional element
T5 team – BAA Retail	Airside retail area (in main concourse building) ~15,000 m^2 of shops, duty free (3000 m^2), catering, toilet blocks, circulation, support space, storage
T5 team – BA	Check-in area (in main concourse building) ~100 check-in assisted desks with baggage acceptance, 50 desks with bag drops, 100 self-service check-in kiosks (in 2005) Aircraft stands ~60 aircraft stands (in 2005)
T5 team – NATS	Visual control room Area for air traffic controllers' workstations and IT cabinets

In May 2004, one of us (Gil) obtained access to the T5 project after undergoing an induction. Gil was given a pass to enter the site, desk space, telephone directory, restricted access to the project intranet, and taught how to build T5-related e-mail addresses. Access to the intranet enabled us to examine the design briefs and standards, project procedures and schedules, subproject execution plans, and progress reports; no access was granted, however, to the spreadsheets showing the costs of effecting design changes, as this was deemed commercially sensitive information. Between Spring 2004 and Summer 2007, Gil visited the project regularly, spending up to 5 days per visit on site. From the outset of the fieldwork, we knew that the notion of design fluidity was influencing the project management of T5, since BAA staff had documented the use of design postponement – the 'Last Responsible Moment (LRM)' in their jargon – as early as 2000 (Lane and Woodman, 2000). How BAA was seeking to balance investments in flexible architectures and conventional risk management practice was not known, however.

For data, we relied on primarily on interviews and archives. Drawing on two frames of reference (Van de Ven, 2007), risk management and design flexibility, we undertook 67 formal, semi-structured interviews, lasting 1–2 h. Our key questions to the interviewees, which are summarized in Appendix together with a list of their job roles, were sent in e-mails requesting interviews. After the first campaign of interviews, we constructed event-driven narratives for the subprojects, with gaps in understanding being addressed through subsequent interviews and informal conversations. Further interviewees were identified through a 'snowball approach' (Biernacki and Waldorf, 1981): once a relevant instance of co-design surfaced in a conversation, the interviewee was asked to suggest colleagues (including personnel working for other stakeholders) who could complement his/her viewpoint. Issues of internal validation and inherent bias were handled by, first, sampling units of analysis from different subprojects; and second, by triangulating interview data for each unit of analysis across members of the T5 team, customers and, where appropriate, suppliers. We played interview data against over 100 archival documents, including trade and business press cuttings, design documents, project reports, and field observations. The T5 procedures and progress reports helped to cross-check the respondents' observations. The specifications and drawings were useful to understand the design architectures. The trade press cuttings highlighted the fast-changing nature of the airline and airport industries, whilst site visits elucidated the scale of T5 and issues around staff co-location.

Table 2
Excerpt of data for design flexibility and risk management.

Functional element	Uncertainty in the design requirements	Flexibility in the design architecture	Postponement of design freeze	Exemplars of risk management best practice
Airside retail area	High Retail director: *I've earliest responsible moments – dates before which I shouldn't responsibly make decisions*	Limited flexibility Integral architecture with few allowances built-in	~2002, freeze circulation versus retail spaces ~2004, freeze retail block areas for shops, duty-free, catering, toilets ~2005, freeze subdivision of 150 retail units	Contingency planning: BAA retail director: *I've got a budget from which I can draw to enable change*
Check-in area	High BA project director: *We knew self-service check-in would grow, but couldn't tell how much*	Limited flexibility Hybrid architecture with loosely coupled elements (check-in desks) and tightly coupled elements (bag drop-offs)	~March 04, freeze layout for 84 assisted desks, 54 desks with bag drop, 65 self-service kiosks ~July 04, freeze layout for 100 assisted desks, 50 desks with bag drop, 100 self-service kiosks ~2006, change layout to 80% self-service check-in	Rejection of design change: BA designer: BAA is digging their heels now [2/2005], and saying 'no more changes'
Aircraft parking stands	High BA project director: *Our aircraft procurement policy changes every year*	Limited flexibility Integral architecture with a few built-in allowances, e.g., 4 dual-use stands	~2002, freeze stands layout based on the fleet and schedule in vigour ~2003/04, rework stands layout after major change request ~2006, BA starts new aircraft fleet review	Early freeze of the design brief: Airfield head of design: *we get forecast updates every so often but we drew line on the sand, and said –'we'll develop the brief based on this forecast'*
Air traffic visual control room	High NATS project director: *we were absolutely convinced that things were going to change*	Flexible design Mostly modular, with some additional allowances built-in	~Feb 05, freeze design of the main structure (tower and cap) ~Jan 06, freeze design of the layout for the controllers' workstations	Strong front-end strategizing: NATS project director: *we can say that 90% of what was written in day one still applies to date*

Reliability was addressed by adopting a strict research protocol. The interviews were transcribed and organised into a database, with write-ups developed for each case. The authors started data coding by aggregating data using sensitizing categories, such as modularity, safeguards, front-end strategizing, and governance, from our two cognitive filters (Helson, 1964). We sifted through data manually, populating matrices with data excerpts across the cases. As we interacted with the data, new relevant codes emerged (co-location, team continuity, co-operation). The coding of data was initially verified by a third scholar with knowledge of the two frames of reference but who did not participate directly in the study. It was also tested and refined through numerous presentations and drafts. To make sense of empirical data (Langley, 1999), we also constructed graphical displays that show how particular constructs were realised (governance, postponement). By playing data against theory, we conceptualized a complementarity between risk management and design flexibility in managing major projects. We tested the plausibility of the relationships that we derived with the help of matrices displaying cross-case comparisons (Miles and Huberman, 1994). Tables 2, 3 and Figs. 1–3 include data exemplars, and illustrate the analysis.

4. Analysis: rething the management of major projects

As highlighted earlier, BAA's top management was mindful from the outset of the T5 project that huge budgetary and schedule overruns often characterised major projects. Without significant

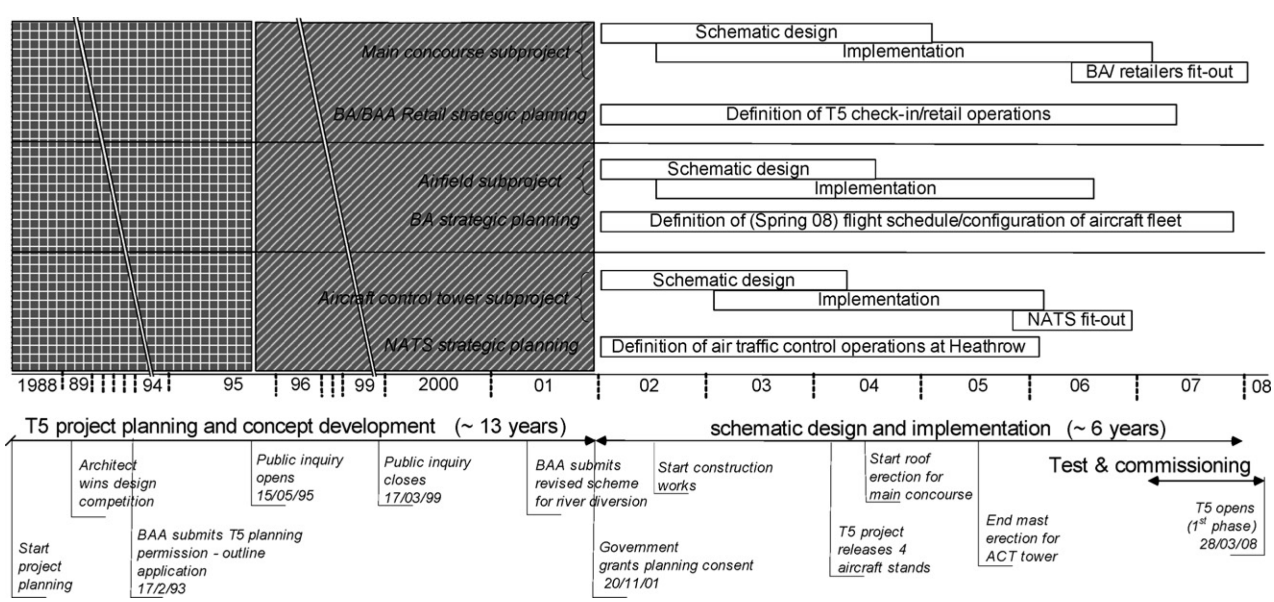

Fig. 1. The timescale for schematic design and implementation of Terminal 5.

Table 3
Excerpt of data for co-design, developer–customer tension and co-operation.

Functional element	Implementing Co-design		Tension in the interaction between the developer and customer illustrated with exemplars	Co-operation between the developer and customer illustrated with exemplars
	Physical proximity of project developer and customer teams	Continuity of personnel over project time		
Airside retail area	Teams located in different buildings connected with frequently scheduled shuttle service (~10 min travel time)	Both project teams and top management stayed in post throughout the project T5 retail director: *It [continuity] earns you the right to sit at the table*	Moderate; T5 subproject leader: *It's easier for them [retail] to go into irresponsible moment* T5 retail director: *They [T5 team] wanted decisions by this date, I said I could deliver by this date... they tend to ignore me when I say 'I can only give you an assumption'*	Adequate; Working for same firm helped BAA Retail director: *I think we got the balance right, and the fact we're running like mad to finish the project on time – we will, but it will be tough – that suggests to me that at a strategic level, the LRMs and progressive fixity were timely*
Check-in Area Aircraft parking stands	Teams co-located in the same building	Project teams stayed in post throughout the project, but frequent changes at BA top management	High; T5 design manager: *It's difficult to ask people to decide 3, 4 years before T5 opens, but we explain we're pouring concrete next week* BA project director: We're making our check-in processes fit the building, and that's not the way it should be T5 head of development: *What I'm saying now [2006] to BA is 'we aren't going to change our stand sizes again* BA project director [2005]: *I tell them [T5 team] It's impossible to predict the configuration of our aircraft fleet in 2008*	Inadequate; Gap between interests not bridged BA senior director [04]: *It has been 'we and them', there's a sort of fence around, it's not inclusive as it should be. BAA has been successful in cooperative work with its first-tier suppliers, but they've not taken that to the way they treated their tenant*
Air traffic visual control room	Teams located in different buildings, but connected with scheduled shuttle service (~20 min travel time)	Both project teams and top management stayed in post throughout project time	Low; T5 project leader: *The technology that goes inside changed immensely, but the structure remained the same* NATS Head of Engineering: *Only the rotating podium had some design impacts, but that went away*	High; Business interests reconciled at front-end strategizing NATS Head of Engineering: *Between ourselves and the design team, we're meeting and exchanging information fairly regularly; then we slowed down, and now [06] we're running once a week meetings as there are many things to agree on site; so anytime we've information that needs to be exchanged, it's easy to do it*

change, they feared T5 would follow suit. Central to rethinking project management in T5 was the idea of implementing a co-operative approach between the developer and customers that could be sustained throughout the many years needed to design and deliver the terminal (Fig. 1). Fulfilling its commitment in the planning application to adopt a 'customer-focused attitude', BAA involved the T5's key customers early on in the design process. The T5 team was tasked with helping customers to identify their needs and prioritize their preferences. Further, the T5 design briefs – the documents spelling out the schedule of works needed, adjacencies between functional areas, and operational requirements – were co-created and signed-off by the T5 team and relevant customers. To help facilitate this co-operation, the T5 team also co-located itself on the project site with the key project teams for the customers, a practice associated with high-performing teamwork (Clark and Fujimoto, 1991; Hoegl and Proserpio, 2004). Moreover, the T5 team invested in 3D prototyping, creating the Single Model Environment, a technology which offers visualisations and fly-throughs that have been proven useful to removing ambiguity and accelerating problem-solving in design (Boehm et al., 1984; Terwiesch and Lock, 2004).

The T5 team also recognised that customers wanted to keep refining some requirements during the project, and therefore the schematic design for some elements had to stay fluid. To achieve this, the developer adopted a design postponement strategy similar to that outlined in accounts of product development at Toyota (Clark and Fujimoto, 1991; Ward et al., 1995); its aim was to fix progressively the schematic design, with the various design elements being frozen at the 'last responsible moment' (LRM). The T5 team set the LRMs, and communicated them to customers as the dates by which selected works had to start to avoid disruptive 'knock-on' impacts on the overall project costs and/or schedule (BAA, 2001) (Fig. 2). To operationalize this strategy, a stage-gate approach was adopted (Cooper, 1990), with each subproject team required to produce an execution plan that defined for the main elements, construction methods, baseline budget and schedule, and risk management strategy. These plans were approved in D-day reviews, after which BAA released funding for implementation. Before D-day, the procedural name for the LRMs, the (schematic) design could flex to accommodate changes at no cost to the customers; after D-day, 'the design should be put to bed, finish' in the words of a senior design manager.

The strategy to fix progressively the design on set LRMs acknowledged that postponing design freeze for certain features could be business-critical for customers, and sought to accommodate this whilst also minimizing the reworking of the elements that

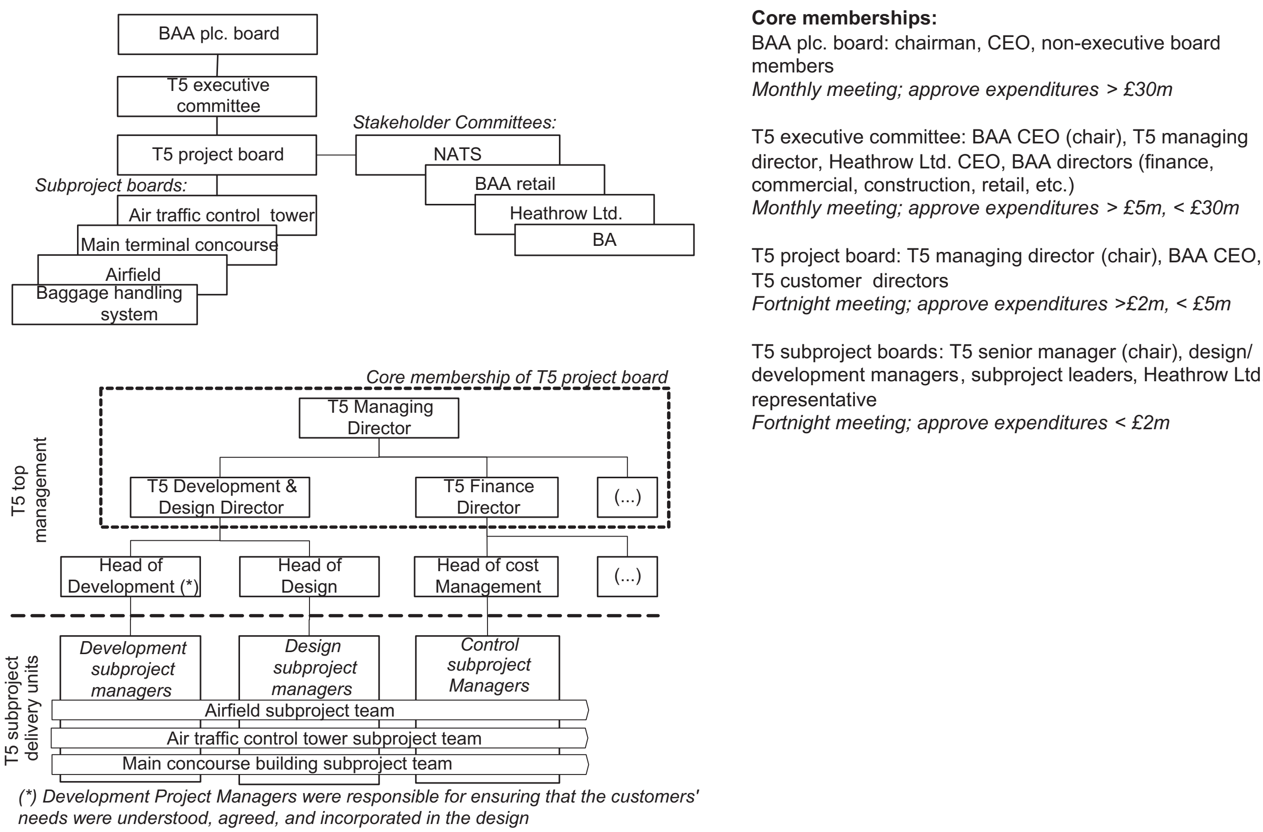

Fig. 2. The governance structure for the T5 project.

needed to be designed, detailed and built first for physical reasons (e.g., foundations). The T5 team was aware, however, that initiatives to encourage co-operation with customers would not eliminate inter-organisational conflicts over the project time. For example, setting LRM dates during the early stages was challenging because the customers had not finalised the design of their future operations, and sought to delay this as near as possible to 2008. As BAA's director of T5 design explained:

> "The business of delaying decisions is exactly what our customers want because this is a changing world. Inevitably, that means we're going [into implementation] with a set of assumptions that may not come true. The difficulty with LRM is to convince people that the decision is really needed. What I say is 'I'm hearing what you're saying, but this is by when we need you to decide in order to open [at the end March 2008]"

Thus, to reduce the number of late customer-driven change requests and manage the anticipated risks of co-design more generally, BAA complemented the implementation of design postponement with conventional risk management practices (Cleland and King, 1983). It established a governance structure (Fig. 3) consisting of a project board supervising all the subprojects boards; the project board met monthly, included key customer directors, and reported to a T5 executive committee, which in turn reported to the BAA board. This structure acted as an 'umbrella organisation' (Shenhar and Dvir, 1996), delegating authority and accountability to support decision-making and risk management. Change control mechanisms were also implemented, and subproject teams had to produce risk registers identifying foreseeable risks, their likelihood, emergence window, consequences, and costs of (un)mitigated impacts.

Lastly, the team established "The T5 Agreement", a legal contract with the project first-tier suppliers, through which the T5 team committed to reimburse these suppliers on the basis of costs of labour and materials with profit margins agreed ex ante. The T5 Agreement aimed to encourage co-operation, seeking to avoid dysfunctional, 'business as usual' practices, such as wrangling as to whether and to what extent the client should compensate the supplier for rework (BAA, 2001). The suppliers were instead paid for making scope changes (modifications to the design brief) at prices agreed upfront. Because the contract *de facto* guaranteed suppliers could not lose money on T5, BAA insisted it was taking on all the risk – see Gil (2009) for a detailed discussion. Hence, in the T5 context, the critical issues arising from a major change request were: 1. whether it added enough value to offset the adaptation costs and risk of delays; and 2, if the change was deemed acceptable, which party – developer, customer, or both – should pay for it.

Addressing these issues brought to the fore the interplay between design flexibility and risk management, and our data show marked differences in how the two approaches were combined. In one case, the developer invested in a flexible architecture to mitigate the risks of design fluidity; in a second, the risks of progressing with an architecture with limited flexibility were balanced using risk management, whilst in the third, the developer relied heavily on risk management to counterbalance the risks of implementing a rigid architecture. Below, we analyse these processes in detail; we then relate them to whether the developer and customer co-operated during the project. Tables 2 and 3 illustrate the analysis.

4.1. Using flexibility in product design to mitigate risk

The development of the air traffic control tower is an excellent example of how flexibility can be built into large-scale design architectures to mitigate the risks of progressing with uncertain project requirements. A new tower was required because the con-

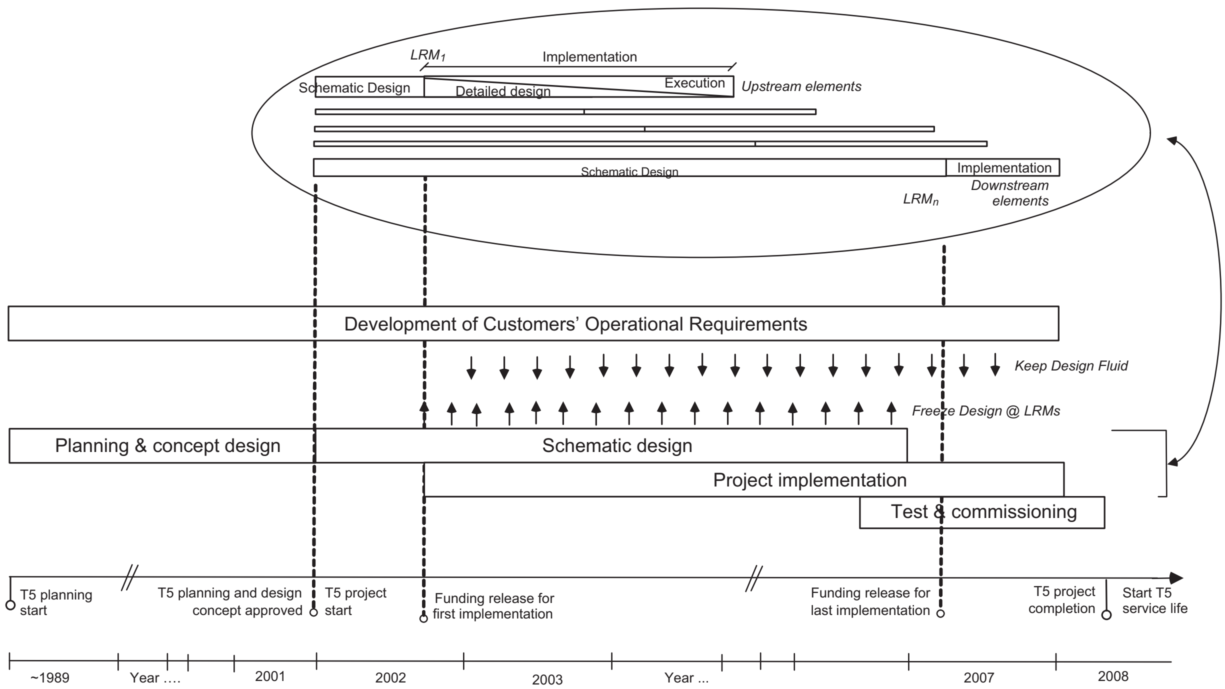

Fig. 3. Application of design postponement ('Last Responsible Moment') to the T5 Project.

trollers' view from Heathrow's existing tower would be obscured by the new terminal. The T5 team was responsible for building the tower, with NATS (the air traffic control service provider) responsible for fitting out the visual control room with radar and other systems. NATS would then lease the new tower for 50 years. For NATS, this represented a once in a lifetime opportunity to fundamentally reconsider the visual control function at Heathrow. With the control room, or cab, sitting on top of a 60 m-high mast, this was a complex subproject, albeit smaller than the concourses or airfield. The execution was challenging since the cab and mast pieces needed to be pre-fabricated to tight tolerances, wheeled into location overnight, and assembled on-site near parked aircraft.

The risk of reworking the mast or cab if the design failed to cope with NATS requirements was therefore substantial. Further, failure to meet the hand-over date would trigger a reduction in the maximum airport charges that BAA could impose at Heathrow. Still, NATS was keen to keep the design of the cab fluid whilst the building of the tower progressed. Given this rare opportunity, the controllers wanted to rethink the control function, which required time to learn about new technologies, visit other recently completed towers, and trial alternative operational procedures and layouts in an off-site mock-up of the new control room. And indeed, by the time NATS commenced fit-out in March 2006, they had experimented with 22 variations of the cab's layout.

To keep the design of the control room fluid whilst constructing the tower, the T5 team and NATS developed a flexible architecture. First, the tower itself was loosely coupled to the cab. This was achieved by incorporating concentric 'trays' under the cab's perforated floor plate to enable services to be distributed to any floor point at a reasonable cost in the future; the central workstations were designed to sit on top of a modular, self-standing steel podium, which enabled to delay the freeze of the controllers' elevation with limited risk of rework; and the risers running inside the mast were sized conservatively. Whilst these two elements remained integral to one another, the allowances safeguarded the flexibility needed to accommodate as yet unforeseen demand for additional services running between the ground and the cab:

> "You always put some contingency in since the tower is going to be there for 50 years. Bearing in mind you don't want cable trays to be too full, you allow [an extra] 50% anyway just for keeping it tidy, and another 25% for future contingency" (NATS project director)

Our findings also suggest the built-in flexibility helped to accommodate unexpected requests that surfaced later such as fitting a visitors' gallery into the cab. Still, investments in flexibility did not eliminate the need for risk management. The built-in flexibility was itself enabled by front-end strategizing. And by building a physical prototype of the cab, for example, the T5 team removed the risk of procrastinating particular decisions, including the quality of the glass, the thickness of the cab mullions, and overlaps in the blinds. The extensive effort to define and freeze early on as many requirements as possible, as well as to identify compelling reasons for delaying specific decisions, was such that the subproject leader compared the co-design process to going on a polar expedition, noting in hindsight: "we had to have discipline in place from day one regarding operational requirements since the design constraints were extreme'.

4.2. Balancing limited design flexibility with risk management

Whilst investing in design flexibility can mitigate the risks of design fluidity, the developer and customers can struggle to accomplish a large architecture that is both flexible and affordable within the time constraint of the early design stage. An alternative is to balance more limited design flexibility with greater risk management practice. This is illustrated by the co-design of the airside retail area under considerable uncertainty due to the fashionable nature of retailing:

> "In the world of retail, anything more than 3 or 4 years out is strategy – a retail brand can be created and decline in 5 years. The degree to which people choose to spend on technology, fashion, restaurants, and cosmetics is volatile. I fixed the subdivision of 150 units in March 05, but chances are some will

decide not to occupy and others will request bigger units" (BAA Retail director)

Retail welcomed the T5 team's early intention to build a flexible architecture into the main concourse. This was business-critical for them as, to maximize retail income, they wanted to keep refining their overall strategy, as well as the retail layout and occupancy scheme. Time was also required to make the best deals with around 140 concessionaires, which were all interested in delaying commitments, first, because any capital invested in shop fittings prior to opening for business would not be earning any money; and second, because they tended to have a last minute culture, with concessionaires geared to avoiding commitments until absolutely necessary.

Both parties agreed to progressively freeze the design for the retail area. All shop fitting was to be completed by December 2007, 3 months prior to opening. Retail agreed to this because it considered LRMs a useful tool in managing the concessionaires and in persuading them to operate within the schedule of the project. But Retail also warned the T5 team of the risks associated with some late but foreseeable commercially-driven changes; and this was exactly what happened, as some deals collapsed and others emerged late in the project. The realisation of this volatility required revisiting some design features that Retail had previously accepted.

Our data suggest that the design flexibility initially built-into the concourse was limited, and critically, it was later further reduced. For example, the floor plate for the retail area was physically decoupled from the building's shell (façade and roof). Yet, the location of the catering and toilet units in the airside retail area remained tightly coupled to the power, exhaust and plumbing utilities, and to floor plate penetrations. As a result, even apparently minor changes, such as moving a toilet block or adding a catering unit, could be costly and disruptive to implement after the layout was frozen. Greater flexibility to re-route utilities could have been achieved had more safeguards been incorporated into the architecture. But, in 2005, when the subproject budget became tight, the T5 team unilaterally designed out some safeguards. This led to some disenchantment in BAA Retail, with one senior member complaining: 'that [flexibility] is a myth. The building was sold like that, but I am not sure it could ever be delivered'. It also brought to the fore risk management practices such as controlling and deferring change.

Two examples illustrate a situation we observed frequently. In the first, an acceptable if suboptimal solution was found to deal with a late change without disrupting the schedule or budget. This concerned hanging large plasma screens on the service towers located inside the main concourse. The notion of 'selling the surface' of these towers had been anticipated in the design brief, and a weight allowance was built into the structural design. Two issues emerged when a brand-owner finally appeared in 2007 interested in this opportunity: first, the proposed screens were heavier than the loads permitted by the design; and second, the budget had no contingency left to erect the screens. Through negotiation, the parties agreed that only screens within the existing tolerance could be accommodated (as retrofitting posed an unacceptable risk of delay) and the brand-owner and Retail agreed to share the cost of installation. In the second example, a late change request was rejected – although Retail was willing to fund the adaptation costs – because the anticipated risk of delay outweighed the value the change was perceived to generate. This was a request, late in 2006, from Harrods, the prestigious retailer, which wanted a glass dome added to the ceiling of its unit to recreate the brand image of its Knightsbridge store. Cost of installation was not an issue, but the T5 team deemed it too disruptive to the project, and moved it to a list of deferred changes. After June 2007, and 9 months prior to T5's opening, both parties agreed that all newly arising risky changes would be placed on a list of deferred changes: 'don't bother to come up with more bright ideas', the Retail Director then told his team.

4.3. Counterbalancing product design rigidity with risk management

To progress a major project with a rigid architecture under uncertainty is risky. Yet, inadequate co-operation between the developer and customer can make it difficult to realize a flexible architecture, directing project management towards risk management practice. The interaction between the T5 team and British Airways (BA) provides an excellent example. BA was and is Heathrow's most significant airline, accounting for about 40% of its flights and passengers. BA would also be the main airline operating from T5, and the two firms worked "cheek by jowl" to achieve planning approval for the new terminal. BA shared foresight and strategic plans for the next 20–30 years, and the T5 team factored this information, for example, with regard to the aircraft fleet configuration and growth of low-cost carriers and e-ticketing, into the design concept that was co-developed for the planning application.

Overall, however, our data suggest that the airline tended to focus on the present and near future. A BA project manager, for instance, complained that others in the airline were so focused on 'today and tomorrow' that they weren't interested when he asked them, 5 even 3 years away, "what's your vision of passenger handling for T5?"' BA also found it hard to predict the speed at which changes would occur, and often in the absence of a clear vision from the airline's top management team, BA's project staff co-wrote the design briefs on the basis of current practice, despite anticipating some substantial changes. In other occasions, rather than commit to what might be erroneous expectations, the airline's project staff sought to delay decisions:

> "They [BAA] take 5 years to give a new terminal to us – our response times are at odds with each other. I can only tell them what my requirements are for the next 2 years because they'll change when T5 opens. So we need to make decisions as late as possible." (BA's T5 project director).

In late 2005, and under the leadership of a new CEO, BA's top management framed the move to T5 as a 'catalyst for change'. The operations director was given overall responsibility for the airline's "Fit-for-Five" campaign, aimed at fundamentally reforming working practices at Heathrow. Some of the proposals that then started to surface conflicted with the design already being implemented, and the need to reset LRMs, as well as to reopen decisions and unfreeze the schematic design for some completed functional elements, became business-critical.

The co-design of two elements illustrates the instability in BA's requirements, and its inability to commit to, or at least communicate, a long-term vision. In 2004, BA agreed to freeze the design for the check-in area on the assumption that half of the check-in points would be self-service kiosks. Late in 2006, it sought to move to 80% self-service check-in, assuming half its passengers would print their boarding passes prior to arriving at the airport. A second example relates to the configuration of the aircraft stands. The number and size of the stands should ideally relate to the size of the aircraft using them: a wide-bodied A380 superjumbo, for example, requires a much larger and wider stand than a narrow-bodied A318. Accordingly, the T5 team needed information about BA's plans to renew its aircraft fleet, including the number of small and large aircraft, and ideally the individual types of aircraft. BA's plans with regard to the Airbus A380 superjumbo (which belatedly entered service in October 2007) were particularly relevant. As a long-haul operator based at a severely congested airport, BA was expected to be an early customer for this aircraft. BA, however, delayed making any commitment to the type until September 2007, just 6 months prior to the opening of T5. BA's intentions with regard to its aircraft fleet may have been genuinely unstable and, from its perspective, aircraft purchasing decisions had to precede decisions about the stand layout – if stand choices revealed BA's strategy, this would undermine its bargaining position with the aircraft manufacturers. However, BA's unwillingness to share strategic thinking posed a dilemma for the T5 team: if T5 were built with stands intended for the A380 but BA did not adopt it, then valuable stand space could be wasted, whereas if BA adopted the type but T5 lacked suitable stands, service quality at T5 would suffer.

Our findings suggest that T5's architectures seldom exhibited enough flexibility to accommodate BA-driven changes at low risk of overruns. For the check-in area, the T5 team 'prudently' invested in a high-density utility grid running under the floor. This safeguarded flexibility to cope with changes in the location and number of self-service kiosks. But bag drop-offs remained tightly connected through the holes in the floor plate to the baggage handling system in the space below. Likewise, the design of the stands had little flexibility to adapt to changes in the configuration of the aircraft fleet. Stands were designed adjacent to one another and to taxiways, and each concrete stand had many utilities and the foundations for the towers supporting the air bridge embedded into it.

To project manage risk, the T5 team insisted there was limited slack to reset LRMs, and accommodate late change. They argued that resetting LRMs would disrupt the schedule, and shorten the testing and commissioning period. They also insisted that all change requests should go through a formal process, being first assessed by the T5 team, and if the risk of undertaking a change was deemed acceptable, BA should bear the adaptation costs to protect the project budget. Our data indicate this procedure was effective in mitigating the risks, but tended to lead to suboptimal design solutions. For example, in the case of the check-in area, the teams agreed to compromise by converting some of the assisted check-in desks into bag drop-offs, but with a loss of physical adjacency between some drop-offs and the self-service kiosks. This compromise arose because the T5 team asserted that it was too late to change the layout of the baggage handling system in the space below. In relation to the aircraft stands, the design went through significant changes in 2004 after BA asked to consolidate all of its operations at T5 immediately on its opening. This request, for 'single terminal occupancy' (STO), intended to improve efficiency and reversed the plan agreed that BA would move 20 million passengers per annum (mppa) from the existing terminals on T5's opening, with the remaining 7 mppa moving in when the second satellite terminal opened between 2012 and 2015:

> "STO [Single Terminal Occupancy] was our [BA] initiative... Originally, we said 'We'll only put the traffic that we can comfortably handle [in T5].' Two years ago, different people took a different view of that balance, and said 'we'd rather handle 20% more passengers" (BA designer 2006).

The BAA board approved the STO change because it saw this released space in Heathrow's other terminals, which could be remodeled to provide competitive facilities to other airlines and meet their demands for service-level parity with BA. Yet, STO reportedly cost £100m, and took 8 months to 'shoehorn' into the project. When BA announced a new review of its aircraft fleet in 2006, they were told bluntly that the T5 team would not accept any further request to change the configuration of the aircraft stands before 2008 since the risk of disruption was deemed too high. BAA also noted that it reserved the right to make any underutilized T5 stands available to other airlines, a stance that reflected the growing antagonism between the two organisations.

4.4. Co-operation between developer and customers: easier said than done

As mentioned earlier, central to re-thinking project management in T5 was forging close and sustained co-operative ties between the developer and customers. Our data, however, indicate significant variation in the strength and success of these co-operative ties. Crucially, we find the strength of the relationships conditioned the developer's willingness to invest in design flexibility, with stronger relations being associated with more flexible architectures, and weaker, fractious relations being associated with an emphasis being placed on risk management practices.

In the case of NATS, this organisation faced a stable, secure environment – it was going to lease that control tower for 50 years – and top management recognised the 'once in a lifetime' opportunity presented by the new tower. Our data suggest managerial attention was sufficiently focused on this opportunity to grasp it by working closely with the T5 team. The relationship was initially somewhat distrustful: "In 2001, the feeling I got was that they [NATS] didn't trust us and vice-versa, and neither trusted the design team. People didn't believe in my willingness to develop the best tower", recalled BAA's subproject leader. Yet, the relationship developed into a 'fabulous level of understanding'. Interviewees from both parties repeatedly asserted that this was helped by continuity of key personnel in both teams, and although not co-located in the same building, they were close enough for frequent formal and informal face-to-face meetings. Weekly inter-firm rolling meetings were organised, and both teams regularly attended the design meetings internal to the other. The 3-D model also proved useful to ground numerous informal, impromptu discussions. This co-operation enabled a rich and timely flow of information between organisations, including understanding future scenarios, their likelihoods, and the pros and cons of design alternatives. This, in turn, encouraged capital investments in product flexibility, as the T5 team felt these were a sensible and justifiable way to insure against possible futures.

BAA Retail provides an interesting intermediary case. Retail was certainly an important business unit, as retail and catering tenancies contribute about a third of BAA's total revenues at Heathrow airport. In this case, the teams were located in buildings not far apart, and the key project personnel remained stable throughout. As both parties were working for the same company, they were able to share commercially sensitive information about T5's retail strategy, and these insights encouraged the T5 team to make some investments in design flexibly, particularly through the use of safeguards (Gil, 2007, 2009a). Yet, the harmony of this relationship deteriorated after a mid-term project review estimated the buildings subproject would overrun its budget unless cost-cutting measures were undertaken. In response, the T5 team unilaterally designed out some of the allowances, reducing flexibility; they also became increasingly reluctant to further delay commitments and accept late changes. Faced with a growing misalignment of interests, co-operation between the two parties became strained, and negotiations fraught ('phone calls started, the e-mail got a bit hotter'). To resolve the issues, a joint working group was set up, and both parties met weekly to appraise the benefits and risks of any emergent change. Retail also agreed to incur the adaptation costs of some late changes that were deemed acceptable. And 9 months prior to opening, shared awareness that further changes could not be accommodated without derailing the project, meant both parties agreed not to implement any new change even when funds were available. Overall, BAA's Retail Director was satisfied that they had had their say: "We had a voice and the right to sit at the table discussing the gray areas of the design".

The case of BA is very different. After working co-operatively through the public inquiry, the T5 team and the BA team on the project decided to remain co-located in the same building for the rest of the project mindful that BA's business environment was extremely unstable to the extent the airline seemed to fear for its very survival. Overall, our data suggest that BA top management recognised T5 could act as a 'catalyst' to change practices at Heathrow airport, but it was too busy fire-fighting to give the project the attention it required. This fuelled short-term thinking, which was exacerbated by the high churn amongst top managers. As a result, whilst the T5 team was interested in progressively freezing the design, BA was interested in keeping the design fluid for as long as possible. Faced with a misalignment of interests, co-operation deteriorated, with both parties complaining that the other was not fully adhering to the co-design process:

> "Here we're involved, but only when it suits. We need to do a lot of digging and fishing. People should be completely honest, open, address all issues together . . . [but] when two major blue chip companies have slightly different agendas. . . maybe this is the best we can get" (senior BA representative 2005)

BA's inability to provide a clear vision was perhaps understandable, given its top management was distracted by a series of series of crises: 9/11 (2001), the Iraq war that followed, and the 2002-03 East Asian SARS epidemic. Furthermore, 'full-service airlines' like BA were struggling to meet the challenge of 'low-cost' carriers, an 'open skies' agreement on transatlantic routes (which came into force in February 2008), and the growth of airline alliances. From the T5 team's perspective, however, BA seemed to be seeking to delay critical design decisions and request late but significant changes without what they regarded as full justification. BA, meanwhile, felt the T5 team was hiding slack in the programme, a belief that was encouraged when the airline succeeded in having some changes implemented after the 'last responsible moment'. As one BA senior director observed: 'It's unfortunate that no one here trusts LRMs and games are being played. If they [the T5 team] know there's a risk one party is going to miss a LRM, they'll bring it forward. So we say they're gaming, and that we don't need to hit the LRM'.

Interestingly, the relationship between the T5 team and BA's project team remained strong, aided by co-location and continuity in key project staff. The latter even acknowledged that they filtered design change requests from BA's top management, shielding the T5 team from the 'absolutely barking stuff'. And when addressing the tension between the two parties, a member of the airline's team was more sympathetic to the T5 team than to his own employer, noting:

> "LRMs worked all right until we [BA] suddenly changed direction. We've this churn of people around, new directors and general managers, and new appointees don't live out the decisions made by the predecessors.. BAA has been very responsive. If I were in their position, I'd have said 'get lost' a long time ago."

The problem was that BA's project team was not empowered enough to share commercially sensitive information or make bold decisions about future operations for T5. Occasionally, they were not aware of the airline's plans. Instead, they would sometimes agree to decisions on the basis of unchanged practices, despite anticipating change. Starved of reliable information and without the support of an empowered local customer team, BAA's T5 team became increasingly reluctant to further delay commitments, and increasingly resisted BA's change requests, despite the airline's commercial interests. The T5 team also became averse to invest in design flexibility, imposing instead a more restricted view on the T5 design that stoked resentment and frustration within BA, with some considering T5 not 'fit for purpose'. Overall, relations became adversarial (with 'big fights'): "We were bad bedfellows", reflected BA's project director in hindsight.

5. Discussion

We have analysed three cases in which design flexibility and risk management were combined to deliver major, one-off assets under conditions of uncertainty in requirements. The cases highlight variety in the way these two approaches can be combined, and crucially, the orientation to one or other appears conditioned by the extent to which developer and customer co-operate and keep their interests aligned over the project time. Figs. 4–6 trace in stylised, temporal schemas, three propositions which exhaust conceptually the variability that we observed empirically.

In the first scenario, which accords most closely to the NATS case, investments in design flexibility are used to mitigate the risks of design fluidity, and as a result, late change requests to enhance effectiveness are dealt with efficiently (Fig. 4). To achieve this scenario, developer and customer must develop and share a long-term vision(s), and sustain co-operation. This enables them to: 1. identify and agree on the design elements that must be frozen early on and those required to remain fluid; and 2. invest in modularity and safeguards. Our findings reveal nonetheless that design flexibility and co-operation cannot anticipate all eventualities, and some change requests outside the designed-in flexibility still emerge, requiring risk management.

A second scenario, derived from the Retail case, places greater emphasis on risk management to offset an architecture with limited flexibility (Fig. 5). This relates to the difficulty of achieving and keeping affordable a flexible architecture even when the developer and customer co-operate and share understanding of foreseeable futures (Sommer and Loch, 2004) and of the way their realisation can impact design. The balance between flexibility and risk management helps to reconcile efficiency and effectiveness, but it is more likely to lead to suboptimal outcomes.

The third scenario, drawn from the BA case, emphasises conventional risk management practices. The need for these arises because the developer and customer fail to co-operate effectively throughout the project due to a misalignment of interests. The failure to forge a shared long-term vision, transforming uncertainties into foreseeable possibilities, makes investments in design flexibility hard to justify; consequently, project management shifts the emphasis toward risk management practices, with concerns for efficiency dominating over long-term effectiveness.

Overall, this emergent theoretical understanding adds to literature on the management of major projects by placing product design and the developer's relationship with customers at the heart of discussions of how to reconcile efficiency and effectiveness in these projects. An important debate in this literature is whether the schematic design should be frozen early on, after front-end strategizing, with strong governance and control procedures used to reject subsequent change requests (Morris and Hough, 1987; Floricel and Miller, 2001; Morris, 1994), or whether an evolutionary approach should be adopted, whereby the delivery process is more accommodating to external events that occur as the project unfolds (Dvir and Lechler, 2004; Gil et al., 2006; Miller and Lessard, 2007). Our inductive, temporal study shows that effectiveness and efficiency can be balanced by embedding in essentially integral architectures flexibility, through modularity and safeguarding, alongside the use of risk management practice. Crucially, the developer's willingness to invest in product design flexibility is conditioned by the quality of its relationship with the customer.

In keeping with the literature on project risk management (Morris, forthcoming), our findings suggest front-end strategizing is critical to creating the opportunity to build-in product flexibility. This does not mean flexibility will be realised. Modular architectures are notoriously difficult to achieve for mechanical and structural systems (Whitney, 2004). Modularity and safeguards also require capital investments that may not be affordable (Baldwin and Clark, 2000; Gil, 2007, 2009a). Further, the analysis shows that even when flexibility is built in, it cannot substitute the need for governance and change control to deal with unplanned change requests (Sommer and Loch, 2004; Dvir and Lechler, 2004).

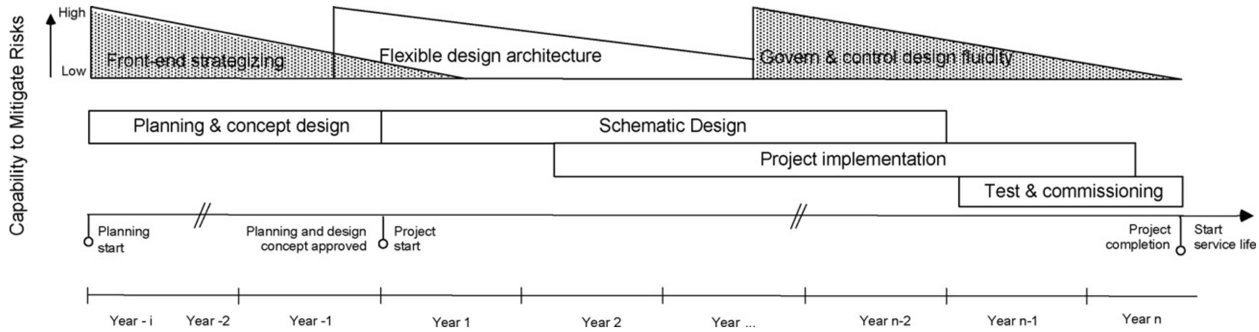

Fig. 4. Use of product design flexibility to mitigate risks of design fluidity (Scenario I).

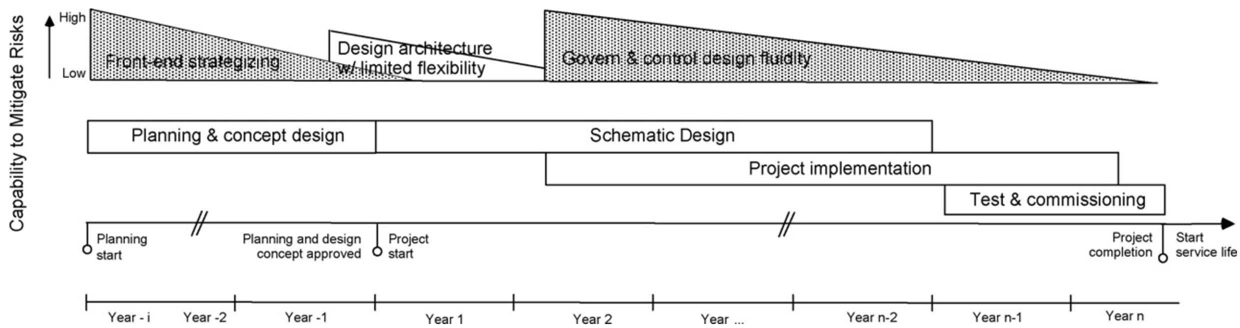

Fig. 5. Balance of limited flexibility in product design with risk management (Scenario II).

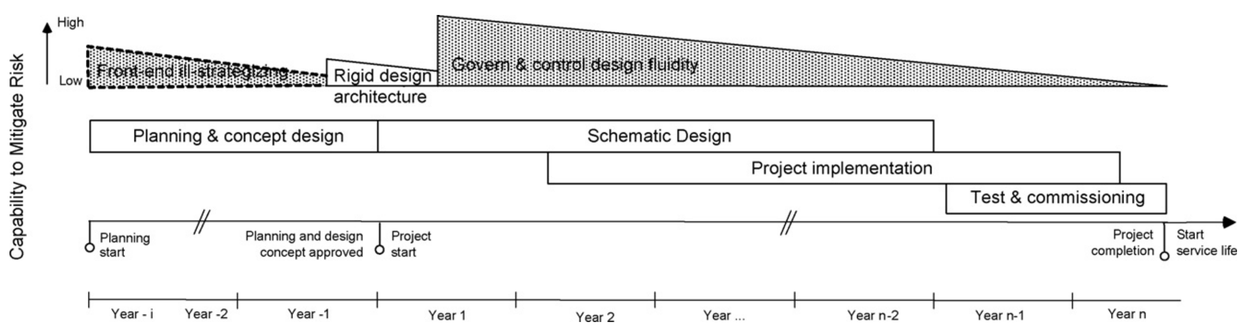

Fig. 6. Counterbalance of front-end ill-strategizing with risk management (Scenario III).

At the limit, to manage risk, developers need to reject change. This is akin to 'generational learning feedback' (Eppinger, 2001), which argues that redesign in product development becomes wasteful beyond a certain point, and that teams should instead launch the product as designed (if the flaws are minor), or abandon it altogether. Abandoning major projects nearing completion is rarely an option (Hobday, 2000), so implementing a suboptimal design is valid, particularly if both parties want to stay within the original budget and timescale.

Our analysis also points to the key insight that the quality of the developer's relationship with the customers can vary significantly, which has been underappreciated in major project studies, which tend to take customers as a homogeneous group that needs to be managed (Morris, forthcoming) and allowed to shape outcomes (Miller and Lessard, 2007). Variability in these relationships should not come as a surprise. What decision-makers do depends on what they focus their attention on, whilst what they focus on depends on the particular context or situation they find themselves in (Simon, 1947; Ocasio, 1997). And our study shows different customers can operate under significantly different environmental uncertainties and strategic horizons. But, essential to our understanding of managing major projects, our study suggests that if developer and customer fail to share goals and exchange information – core attributes of co-operation in projects (Stinchcombe and Heimer, 1985; Clegg et al., 2002) – uncertainty becomes much greater. This insight indicates that uncertainty in major projects is not wholly exogenous as it is often supposed (Dvir and Lechler, 2004; Gil et al., 2006). Instead, uncertainty in project requirements is influenced both by the quality of the developer's relationship with the customer, and by organisational arrangements put in place between them.

Our study also illuminates the antecedents of the co-operation condition. It suggests co-operation is less challenging to sustain if customers can be generous in sharing and timely updating a vision, or a credible spectrum of visions, with less fear information will be taken up by rivals. Not surprisingly, it helps if the customer operates in a non-competitive environment (the case of NATS), or if both parties work for the same business, thereby internalizing the costs and information ownership (the case of Retail). Our findings also show that co-operation requires that both parties keep their interests aligned. This can be difficult to achieve, however, when the customer operates in a volatile environment. Economic and management upheavals can distract customers accustomed to working with short planning horizons, limited foresight, strategic shifts, and frequent changes in the top management team, in striking contrast to the developer's steady concerns for project efficiency. Finally, our data show that continuity of project staff and their co-location – a baseline across all our cases – are inadequate conditions to guarantee co-operation. Taken together, these insights contribute to understand accounts of major projects progressing with rigid architectures under high uncertainty, some of which relate to dramatic overruns or ineffective outcomes (Ross and Staw, 1986; Genus, 1997). Interestingly, to date, the literature on major projects has focused primarily on the interface between developer and suppliers, and argues that relational contracts enable long-term co-operation under uncertainty (cf. Henisz and Levitt, 2009; Gil, 2009; Stinchcombe and Heimer, 1985). Here, our interest has been on the customer–developer interface, which is not one necessarily between firms. It remains indeterminate, however, how formal and informal relational contracting strategies can enable co-operation at the upstream project interfaces.

5.1. Ties to design flexibility

Overall, our insights are consistent with studies on the costs of product design flexibility. Suh et al. (2007), for example, estimate that the capital cost of developing a flexible car platform can be 30% higher than that for developing a rigid one. In effect, existing studies show modular architectures require a delicate decision to balance how much to invest upfront in de-coupling functional elements against the adaptation and coordination costs later on (Ethiraj and Levinthal, 2004). Likewise, the capital cost of safeguards can be hard to justify if they involve difficult trade-offs due to a tight budget, or if their utilisation is oriented to events in a distant, ambiguous future (Gil, 2007, 2009a). In the context of major projects, we illuminate the difficulty of determining how much to invest upfront in flexibility. Whilst these investments can be framed justifiably as an insurance against foreseeable futures (de Neufville and Scholtes, forthcoming), they may be unaffordable if any or just a very small proportion of that flexibility can be expected to be ever exploited over the asset's project delivery and operating lifecycle. Wary of wasteful investments, developers under-invest in modularity and cut back on safeguards before implementation. As the project progresses with a rigid architecture, the risks of derailing it to respond to business-critical change then become enormous.

Interestingly, studies on design flexibility in product development largely frame it as a strategic decision essentially within the control of the developer and its suppliers, and informed by market research (Baldwin and Clark, 2000; Ulrich, 1995; Iansiti, 1995; Thomke, 1997) and competitor analysis (Fixson and Park, 2008). By studying design flexibility in a major project, we unearth how design flexibility can be conditioned by the quality of the developer's relationship with customers. This insight relates to the strand of design flexibility literature that connects organisational designs to 'product' architectures (e.g., Henderson and Clark, 1990; Sanchez and Mahoney, 1996; Brusoni and Prencipe, 2001, 2006; Baldwin, 2008). Departing from Sanchez and Mahoney's (1996) assertion that 'products design organisations' the so-called mirroring hypothesis (Colfer and Baldwin, 2010), scholars argue that modularity can be developed by independent organisations, whereas integral designs must be developed by single organisations. Baldwin (2008) further argues that developers want to ideally create clean breaks between the customers' and developer's design tasks.

This literature addresses inadequately, however, a more nuanced situation in which product architectures are basically integral but hold opportunities to embed flexibility that can increase revenue or customer satisfaction downstream. To seize these opportunities, the customers must get involved ex ante in design, and our study uncovers different organisational designs to accomplish this: NATS, a relatively small organisation of end-users worked directly with the developer; Retail operated as an internal intermediary unit to interpret the concessionaires' interests and balance them with the developer's; likewise, the BA project team was an external intermediary responsible to capture and communicate the airline's interests, and balance them with the developer's.[1] Whilst beyond the scope of this study, it merits investigating under which exact conditions intermediary organisational units are useful, where to locate them, and how to best govern them.

6. Conclusion

By studying the interplay of design flexibility and risk management in a major project, we have bridged a gap between two frames of reference that have developed in parallel. We propose that design flexibility and risk management are complementary in managing these projects. Moreover, we argue that the quality of the developer's relationship with the customer conditions the balance of the two approaches. This conceptualization has managerial and policy implications. It highlights that unless customer and developer sustain co-operation and shared goals, project uncertainty increases and product designs are likely to become more rigid. As managerial complexity compounds, short-term concerns for efficiency can overshadow long-term effectiveness. At the limit, this can lead to early obsolescence and compromise detrimentally the operational longevity of the asset.

Our insights are drawn from cases across a single setting, and we cannot claim generalizability from our findings to the whole universe of major projects. IT projects in particular have made notable progress towards modular architectures (Baldwin and Clark, 2000). The T5 project was also schedule-driven, and BAA was a profit-seeking, monopolistic infrastructure owner operating under public scrutiny. The T5 Agreement between BAA and its suppliers also facilitated greater flexibility in their relationship than is likely to have been the case had a commercially aggressive contract been adopted. These conditions are significant and constitute a limitation. Further studies to test the plausibility of our insights in other contexts are welcomed.

Interestingly, whilst not the focus of this study, the 'debacle' (Brady and Davies, 2010) that characterised T5's opening – when 15% of scheduled flights were cancelled and over 23,000 bags 'misconnected' in the first two weeks of operations – becomes less surprising. The accounts of BAA and BA to the House of Commons Transport Committee (2008) suggest that the bungled opening was caused by the simultaneous realisation of two main groups of risks: 1. inadequate familiarization and insufficient training of airline staff, especially baggage handlers (which BA framed as 'calculated risks', attributing them to compromises it had agreed with BAA to accommodate delays in the building schedule and incompleteness of some essential facilities); and 2. software problems and unserviceable facilities, including lifts, escalators, and toilets (which BAA framed as 'no more than teething troubles'). Critically, the accounts indicate that co-operation between the two companies deteriorated towards the end of the project. Assuming the insights from managing co-design apply to project handover, this deterioration may have stymied exchanges of information essential to manage the hand-over stage, creating instead new and additional risks. With the developer's attention fully focused on delivering T5 on time and within schedule, these risks may well have been overlooked. Testing this logic, of course, requires a further study.

[1] We thank Carliss Baldwin for this valuable point.

A final point of interest, relevant to policy-makers, is how to incentivise monopolistic private developers of public infrastructure assets to build-in greater design flexibility. Importantly, private development of public infrastructure is a growing socio-economic phenomenon worldwide (Gil and Beckman, 2009b). But, as indicated earlier, public and commercial pressure on private developers to deliver capital projects on time and within budget can incentivise managers to make short-term savings, reducing or removing design flexibility, leaving their successors to make amendments (where possible), at greater long-term cost to shareholders and society at large. Given that authorities regulate the price structures and service levels under which monopolists operate, one thought is to factor into the regulatory process mechanisms that encourage design decisions that enhance operational longevity. In the planning stage, the developer could be required, within reason, to build-in design flexibility to pre-specified levels, and later in operations, be permitted to reap the monetary rewards for doing so.

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Appendix A. Appendix

Questions sent in the e-mail to respondents when requesting an interview.

1. Do you face uncertain design requirements in T5? What are these? To what extent are there foreseeable uncertainties, or unforeseeable?
2. What is the role that the project's customers (BA, BAA Retail, NATS, etc.) play in design development?
3. How do you manage design uncertainty stemming from the concurrent engineering nature of the project delivery? What strategies or rules do you use to cope with design change?
4. Do you safeguard design solutions and, if so, when? When do you over design- or over-engineer?
5. Do you modularize design solutions and, if so, when?
6. What scope do you have to postpone design decision-making? What are 'last responsible moments'? How effective are they?
7. Under which conditions do you accept that the design may have to be reworked after it has been 'frozen'?
8. What are your thoughts on the applicability and effectiveness of the T5 agreement to support the delivery of the project, and engineering design work in particular?

Formal Interviews: Job roles of interviewees and number of one-on-one interviews.

T5 team	Supply chain	Customers
Head of development	Project architect	Project director
Project leader (#7)	Project engineer	Project manager (#6)
Director of logistics	Site manager	Chief architect
Senior project manager (#2)	Logistics manager	Head of engineering
Head of supply chain (#2)	Project manager (#3)	Systems integrator
Logistics manager	Acquisition manager	T5 Retail director (#2)
Supply chain manager (#2)	Electrical engineer	Design consultant
Head of buildings (#2)	Project director (#12)	Head of airport systems
Construction leader	Production design leader	Engineer
Production leader (#3)	Design manager (#2)	Property manager
Design manager	Design integrator	Development manager
Contracts manager	Commercial manager	
Subproject leader	Development manager	
Legal director	Head of development	
Engineering integrity director	Mechanical engineer	
Senior development manager (#2)	Airfield designer	
Project manager	Structural designer	
Head of rail and tunnels	Senior systems architect	
Assistant project leader		
Director of design and development		
Head of airfield design		
Airfield project leader		
Head of design		
Interface manager		
Production manager		
Subproject leader		

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