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Citation

Option-Based Risk Management: A Field Study of Sequential Information Technology Investment Decisions

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Communications of the ACM, Management Science, MIS Quarterly, Managerial Decisions and Economics, Information Systems Research, Decision Sciences, and other leading journals and conference proceedings. Dr. Kauffman won best research paper awards at INFORMS CIST in 2003, 2004, and 2005; HICSS in 2004; ICEC in 2005; and the Eighth Information Management Conference in Taiwan in 2006. He is also a 2006 recipient of the IEEE International Society for Engineering Management's "Outstanding Research Contribution."

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ABSTRACT: This field study research evaluates the viability of applying an option-based risk management (OBRiM) framework, and its accompanying theoretical perspective and methodology, to real-world sequential information technology (IT) investment problems. These problems involve alternative investment structures that bear different risk profiles for the firm, and also may improve the payoffs of the associated projects and the organization's performance. We sought to surface the costs, benefits, and risks associated with a complex sequential investment setting that has the key features that OBRiM treats. We combine traditional, purchased real options that subsequently create strategic flexibility for the decision maker, with implicit or embedded real options that are available with no specific investment required provided the decision maker recognizes them. This combination helps the decision maker to both (1) explicitly surface all of his or her strategic choices and (2) accurately value those choices, including ones that require prior enabling investments. The latter permits senior managers to adjust a project's investment trajectory in the face of revealed risk. This normally is important when there are uncertain organizational, technological, competitive, and market conditions. The context of our research is a data mart consolidation project, which was conducted by a major airline firm in association with a data warehousing systems vendor. Field study inquiry and data collection were essential elements in the retrospective analysis of the efficacy of OBRiM as a means to control risk in a large-scale project. We learned that OBRiM's main benefits are (1) the ability to generate meaningful option-bearing investment structures, (2) simplification of the complexities of real options for the business context, (3) accuracy in analyzing the risks of IT investments, and (4) support for more proactive planning. These issues, which we show are more effectively addressed by OBRiM than the other methods, have become crucial as more corporate finance-style approaches are applied to IT investment and IT services problems. Our evaluative study shows that OBRiM has the potential to add value for managers looking to structure risky IT investments, although some aspects still require refinements.

KEY WORDS AND PHRASES: data marts, data warehouses, investment valuation, IT investment, IT services, options, risk management, services science.

strategic options. According to Clemons and Gu: "A strategic option represents a capability to deploy a selected strategy" [13, pp. 15–16]. A dilemma that many organizations face is how to structure such IT investments to optimally control risk and maximize value for the strategies they use. Some choices for this include one-shot implementation, staged implementation, or a pilot effort with a full-scale follow-up effort. Each requires careful consideration of the sequence of IT investment and implementation actions that are appropriate.

We recently proposed an *option-based risk management* (OBRiM) framework to address this issue [6]. OBRiM helps a decision maker to identify which *real options* (i.e., the *implicit options* of deferral and abandonment, and the *explicit options* of pilot and staging that involve some cost to purchase) can be used in an IT investment in order to manage risk and maximize value.[1] OBRiM's logic is that, given the risks specific to an IT investment and the related business setting, embedding carefully chosen real options builds the flexibility needed in case the envisioned risks actually materialize, complementing the implicit options that managers always have at their disposal. Benaroch et al. [9] found that the informal IT risk management strategies of experienced IT project managers are consistent with OBRiM's logic. The framework uses the tools of real options theory from finance to quantify the monetary consequences of risk, to measure flexibility in terms of real option value, and to link these to net investment value. Often, more than one combination of real options may permit controlling the risks affecting an IT investment, consistent with a *corporate finance* perspective on the management of IT projects and infrastructure investments [1]. Because each combination usually has a different associated cost, OBRiM enables finding the most effective combinations of real options for controlling risk and maximizing investment value. Yet, despite these appealing elements of the framework, it remains to be seen whether OBRiM adds value in practice—or if its underlying intuition is enough to support effective decision making.

This paper uses a field study methodology involving interviews with senior managers, collection of data from multiple firms, and additional modeling and analysis to assess the viability of the OBRiM framework and its underlying theory in a real-world setting. Among the questions we hoped to answer for academic research are: Does the framework produce sequential investment structures that managerial users find adequate for controlling uncertainty in critical business settings? Is it feasible to estimate the inputs necessary to evaluate these investment structures using Monte Carlo simulations? Is the use of financial real option models suitable for obtaining firm-specific IT investment valuations? What will be the reactions of business users to sensitivity analysis information that is obtained through Monte Carlo simulations with such models? And, can we understand how do and how should companies identify relevant growth options and estimate their parameters for their business settings? Gaining insight through these questions opens up the possibility for a new corporate finance and risk management tool set for IT senior managers.

This evaluative field study of OBRiM was conducted in the context of a complex *data mart consolidation* (DMC) project aimed at producing an *enterprise data warehouse.*[2] The field study was undertaken with the support of a leading data warehousing vendor, Teradata (www.teradata.com),[3] in cooperation with a major airline whose senior

management was considering such an investment.[4] They were especially interested in structuring the investment to properly recognize the expected costs, benefits, and risks the airline faced. Consolidating data marts enterprisewide is a large-scale IT investment. In 2001, almost all Fortune 1000 companies deployed or planned to deploy an enterprisewide data warehouse [48]. However, such projects are very risky: 50 percent to 67 percent of all initial efforts do not deliver the promised benefits [49].

From a practitioner's perspective, the methods used in this field study research exemplify the new "services science" thinking. In this thinking, innovative tools, frameworks, and approaches are applied to yield actionable knowledge for the management of IT projects, investments, infrastructures, and services. For the present study, the data warehousing vendor's problem was how to help its clients confront investment issues surrounding data mart and enterprise data warehousing projects. The primary applied questions that arose are: How can the long-term strategic value be best understood and portrayed via analysis methods that provide a basis for application in similar contexts and that build upon well-accepted knowledge? How can the value of pursuing different implementation alternatives be understood from the perspective of real growth options they create? What theory-based methodology will enable the data warehousing vendor's clients to evaluate the many alternative implementation choices as sequential IT investments? How should their trade-offs be characterized in terms of the different risks, rewards, and cost components? Is there a methodology for reducing the overwhelming aspects of implementation risk that such large-scale IT investments carry with them? In what ways is it possible to help the vendor's clients understand and quantify the monetary consequences of risk and risk management strategies that can be achieved through innovative approaches to IT investment structuring?

From a researcher's perspective, OBRiM is one of several approaches, including sequential statistical decision analysis, decision trees, and dynamic programming [13], that can be used to structure investments in order to control risk. Our field study also seeks to reveal the advantages and disadvantages of OBRiM relative to these other approaches. The main critique that we offer is that other approaches (1) lack metrics for calibrating risk and (2) do not provide a structured approach that enables managers to identify plausible real operating and growth options. These issues have become crucial as more corporate finance-style approaches are applied to IT investment problems (e.g., [3, 18, 28, 32]).

A broader contribution of this paper is to demonstrate the potential of the OBRiM framework to bridge two main research camps on real options. One camp is high on rigor and the technical aspects of valuing investments using option pricing models. It often overlooks the complexities of applying real options to the kind of projects IT managers actually face (e.g., [46, 47]). The other is more strategy focused. Its concern is articulating managerial heuristics and reasoning processes based on the real options logic (e.g., [13, 20, 21, 36]). This camp recognizes the complexities of applying real options in practice. It typically offers no rigorous approach to configuring the various real options that could be embedded in real projects. To bridge this gap, we show how

OBRiM can simplify the application of real options thinking to real-world IT investments while retaining the quantitative rigor of option pricing models.

Theory

REAL OPTIONS ANALYSIS OFFERS USEFUL theory and methods to address some of the issues that we discussed up to this point with respect to sequential large-scale IT investments. Much information systems (IS) research on real options originally focused on the evaluation of risky IT investments using real options analysis methods from financial economics. Usually, these methods are applied to IT investments that are subject to known risks. These methods also assume that some embedded real options already provide management with strategic and operational flexibility needed to respond to the risks. Real option models have been effectively used to quantify the net value that the flexibility adds in relation to the risks. See Table 1 for sample studies that use this approach and its recent variations.

In spite of the potential benefits that we have suggested, Clemons and Gu note a number of drawbacks on how real options analysis is often applied:

> Valuation of financial options requires existence of arbitrage-free markets where the underlying assets are traded. . . . In its purest sense, a real option is the right to trade a physical asset. . . . There exist no arbitrage-free markets where underlying assets are traded. . . . Even were such assets to exist, this would fail to capture the firm-specific valuation essential to real options theory. . . . Significantly, real options theory, in fact, does not dictate use of any particular pricing models. It is simply an approach that recognizes the value of management flexibility in investment evaluation. [13, pp. 14–15][5]

The methods permit modeling uncertainties and alternative contexts in terms of distributions. This avoids the limitations of *scenario analysis,* which has its own strengths as a qualitative method for IT investment evaluation. This point becomes apparent when we apply methods such as Monte Carlo simulations to generate powerful sensitivity analysis information that is lacking in other approaches. In the research context discussed in this paper, we are able to treat a key question of interest. Can Monte Carlo simulations produce sensitivity analysis information that managerial users will find useful, in association with methods that permit the control of risk in large-scale sequential IT investments?

More recent IS research looks at the link between different risks and different types of real options. Kim and Sanders [30] explain how real options can proactively help us to understand risk in IT projects and to justify project management decisions. This work looks only at three types of options (defer, abandon, change scale), however, and does not focus on any specific list of risks. The OBRiM framework [6] that we advocate, in contrast, offers a more comprehensive and direct way to link the management of various IT investment risks with the use of different real options.

Table 1. IS Literature on Real Option Types and the Related Risks Present

Option	Explanation	Representative IS studies	Risks present
Defer	Flexibility to defer investment commitment is attractive when it enables learning about the nature of uncertain payoffs (and immediate lost cash flows are small).	Benaroch and Kauffman [7, 8]	• Customer usage/acceptance • Vendor adoption • Restrictive legislation
Explore (pilot prototype)	Flexibility to partially invest in a pilot or prototype effort enables learning about the extent to which technical and organizational risks affect the ability to complete (and realize the expected benefits of) a full-scale investment.	Amram and Kulatilaka [1], Kambil et al. [28]	• IS skills and experience • Technology maturity • IT infrastructure adequacy • Organizational adoption
Stage (stop–resume)	Flexibility to stage an investment and kill it midstream (after gateway reviews) is valuable when there are risks due to technical complexity risks, user involvement, architectural compliance, and so on.	Benaroch [6]	• Infrastructural fit • Managerial support, organization adoption • User involvement/support
Change scale	Flexibility to alter—expand or contract—the scope of an investment adds value when it allows reacting to observed conditions concerning technical risk, user involvement risk, and so on.	Gaynor and Bradner [22], Kulatilaka et al. [31]	• Project size and complexity • Technology maturity • Emerging standards

Exit (switch–use)	Flexibility to exit an investment and put its resources to alternate uses provides partial insurance against failure due to client acceptance risk, organizational adoption risk, and so on.	Bräutigam et al. [11]	• Customer usage/adoption • IT infrastructure adequacy
Outsource development operations	Flexibility to outsource development is valuable when development failure risk can be transferred to a third party. Outsourcing a business process is contingent on when business conditions (process transactions load) are sufficiently unfavorable (favorable); transfers benefits risk to a third-party service vendor.	Lammers and Lucke [33], Whang [50]	• IS skills and experience • Cost escalation • Customer demand/usage • Uncertain investment benefits
Lease	Flexibility to lease resources is valuable when investment can be abandoned to save residual resource costs, when abandonment occurs during development, or after investment is operational.	Clemons [12], Clemons and Weber [14]	• Customer adoption • Organizational adoption • Development failure
Strategic growth (expansion)	Flexibility for favorable investment outcomes (due to positive risk) is valuable when the investment creates capabilities and opportunities for follow-up investments.	Taudes et al. [45], Zhu [54]	• Above expected customer adoption/usage rate

The theoretical perspective underlying the OBRiM framework is as follows. To maximize IT investment value, a good manager must size up the relevant risks and proactively build flexibility into an investment. The manager then should continually evaluate new information about the risks, and take corrective actions within the bounds of the flexibility built into the investment—both in explicit option and in implicit option terms. OBRiM formalizes this perspective based on real options theory. It aids in finding a combination of real options or forms of flexibility that add the most value relative to the risks specific to an IT investment. Its main tenets are:

- Real options can be interpreted as high-level strategies for managing risk, with the associated strategic action and a managerial decision that is made possible [1]. Some options are *risk mitigation* strategies, for example, prototyping as a partial investment, which requires some investment up front. Project abandonment is similar; however, it always is available to a management decision maker, so long as there is an active project strategy. From this point of view, both deferral and abandonment have a strategy aspect and a decision aspect. Real options also create *flexibility* needed to deploy more granular risk mitigation steps contingent on the occurrence of risk. For example, deferral can reduce risk due to restrictive regulation with time to lobby for a change in legislation [8]. Similarly, a pilot prototype can prepare a firm for greater commitment later in the face of market uncertainty.
- Flexibility must be proactively embedded in an IT investment based on the specific risks one seeks to control. OBRiM proposes a set of risk option mappings prescribing which real options to embed for which specific IT risks [6, 9]. For example, to control risk due to project size and complexity, the mappings recommend using the stage, explore (pilot prototype), lease, and outsource real options, but *not* the defer and exit real options.
- The real options mapped to for the risks present permit generating alternative investment configurations [6]. Each configuration embeds a different combination of these real options.
- Different combinations of real options affect IT investment value differently, because each may control the same risks to varying degrees and each may have a different associated cost. An economically superior configuration can be found by quantitatively evaluating the different investment configurations using option pricing models.

In order to optimize the balance between risk and value, while considering the cost of creating real options, OBRiM prescribes four analysis steps built on top of the "base case" analysis developed for an IT investment (see Figure 1).

These steps enable senior managers to configure an IT investment using the most cost-effective combination of real options designed for that investment. In comparison to other approaches that can be used to structure investments in order to control risk and create strategic options for the firm, OBRiM is tuned for the *systematic* generation of alternative investment structures. In this way, it may result in the generation of more alternatives. This, however, can present a trade-off, depending on who is evaluating
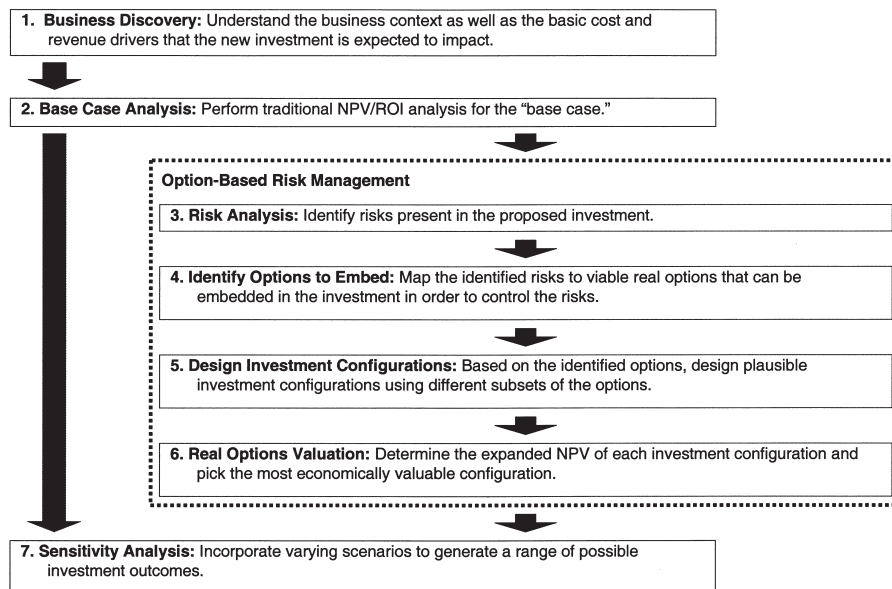
1. **Business Discovery:** Understand the business context as well as the basic cost and revenue drivers that the new investment is expected to impact.

2. **Base Case Analysis:** Perform traditional NPV/ROI analysis for the "base case."

Option-Based Risk Management

3. **Risk Analysis:** Identify risks present in the proposed investment.

4. **Identify Options to Embed:** Map the identified risks to viable real options that can be embedded in the investment in order to control the risks.

5. **Design Investment Configurations:** Based on the identified options, design plausible investment configurations using different subsets of the options.

6. **Real Options Valuation:** Determine the expanded NPV of each investment configuration and pick the most economically valuable configuration.

7. **Sensitivity Analysis:** Incorporate varying scenarios to generate a range of possible investment outcomes.

Figure 1. The OBRiM Framework

this capability. On one hand, the ability to support the risk management–driven generation of alternative strategies and configurations for an IT investment is certainly an advantage. It will help decision makers to surface opportunities that they might not otherwise have thought of. On the other hand, for strategy-oriented investment planning, more alternatives can be a drawback, in the sense of "analysis clutter" and mistaken reliance on a tool to substitute for careful managerial evaluation of strategic opportunities. The onus still is on the shoulders of the users to interpret the usefulness of the real options that are surfaced.

To conclude our discussion in this section, we offer the reader a generalization of our representation of OBRiM. Figure 2 shows the relationships among the major analysis steps that are more generally appropriate for structuring sequential IT investments so as to control their risk and maximize their value. Figure 2 has a number of main elements and subelements, as we have suggested in various ways through our discussion. One is the assessment of the base case investment without real options, resulting in the *passive net present value.*[6] This element also includes risk assessment and sensitivity analysis. The second main element is an assessment of alternative IT investment configurations, and the *active net present value* that results for each alternative. This is done in terms of generation of alternative structures for the various proposed sequential investment actions, risk estimation, and valuation of the real option–bearing investment configurations. The final part involves identification of a superior investment configuration and sensitivity analysis for examining that configuration's ability to control risk.
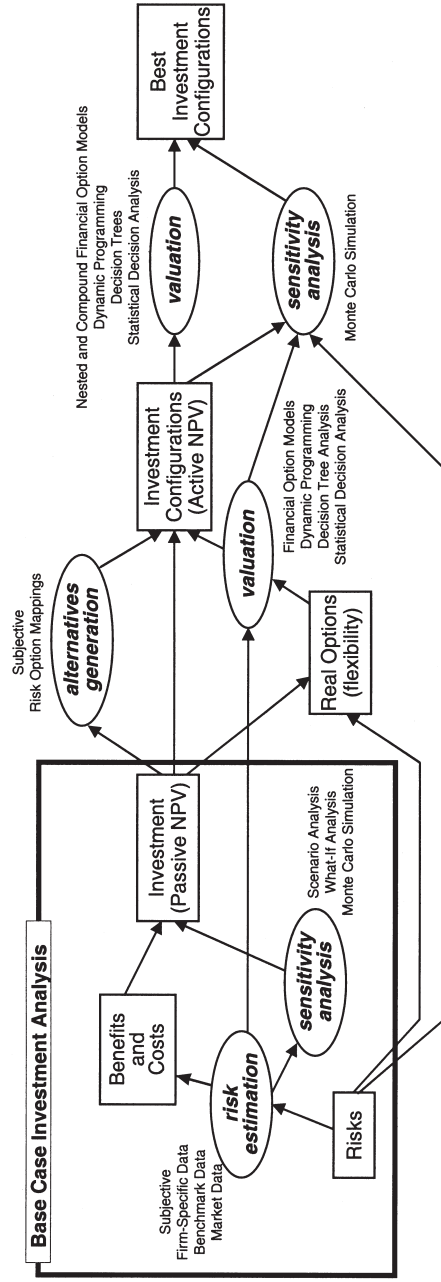
Figure 2. A Road Map for the Activities Involved in IT Investment Structuring for Risk Control

Notes: The two instances where sensitivity analysis is used have different objectives. The one in the base case analysis examines the passive net present value (NPV). The other examines the active NPV of investment configurations embedding options. Although the latter can be applied to every plausible investment configuration, the road map assumes it will be applied only to the configuration with the highest active NPV for reasons of information overload.

OBRiM Applied in a Sequential IT Investment Setting

How should data mart consolidation projects be structured to maximize value? How can the OBRiM framework contribute to our understanding of how to effectively control risk in such large IT investment settings? What specific aspects of OBRiM effectively support the analysis and the management of risk of consolidating data marts as an instance of a typical sequential IT investment? To answer these questions, we will apply OBRiM to a real-world project and assess each of OBRiM's steps (seen in Figure 1) in terms of its value, weaknesses, and challenges for research and practice. The Appendix offers a review of the main issues involved.

Step 1: Business Discovery and Context

The data used in our field study were provided by the data warehouse vendor, Teradata, for one of its client's data mart consolidation project. The vendor's client is a large airline firm, Global Airline. The cost and payoff figures underlying our analysis have been scaled so they are unrecognizable and protect the airline's identity.

Figure 3 shows the airline firm's existing "baseline" data marts. They fall into four clusters, based on a similarity of their technology platform (e.g., Oracle) or relatedness of their business functions (e.g., financial and route tracking optimization). Another vendor's operational customer relationship management (CRM) solution offering campaign management capabilities was deployed earlier with a stand-alone data mart with no firmwide views.

The airline firm hoped to consolidate ten existing data marts and enhance its CRM capabilities. Senior managers recognized that a data mart consolidation would have several benefits. It could lower the cost of operating data marts. It could lower IT expenditures using a data platform from a single vendor. It also might produce better-quality data and a more robust data management platform. Finally, it would likely create follow-up investment opportunities in an integrated CRM solution, which managers identified as the only plausible one in the foreseeable future. Other follow-up investment opportunities not considered include supply-chain applications and business intelligence, for example. As such, it would not make sense to exclude soft benefits such as performance gains due to improved decision-making capabilities that are outside the scope of CRM.

The data warehousing vendor was called upon by its airline firm client to build a business case to enable an accept–reject investment decision, and to configure the investment in light of the expected costs, benefits, and risks. The vendor's staff invited the authors, via Northwestern University, to apply OBRiM, which offered us a useful means to test it.

Step 2: Base Case Analysis

Following the steps in Figure 1, we develop a base case for our analysis. Because we want to evaluate various ways to achieve two separate goals for our data mart
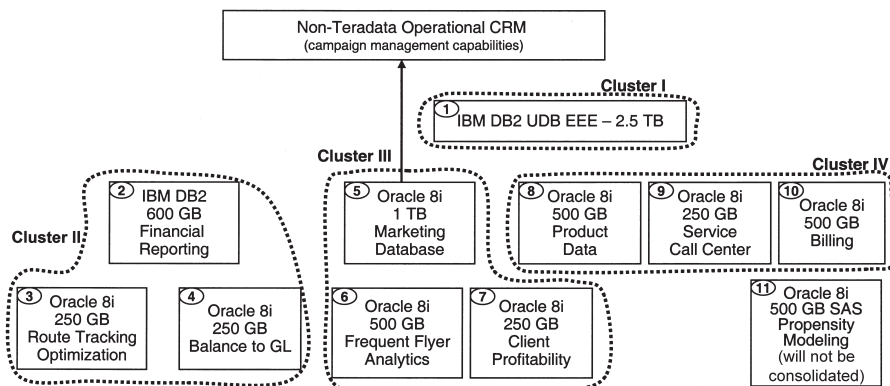
Figure 3. Global Airline's Data Mart Environment

consolidation analysis—rehosting and rearchitecting (see the Appendix)—we actually consider two base cases. These base cases involve no use of real options for risk management purposes.

- *Base Case 1: Rehosting all data marts at once.* This involves simply migrating all ten of the airline's data marts into a single, integrated enterprise data warehouse. The upside of this "big bang" approach was viewed as earlier cost savings from substantial IT personnel reductions and scale economies. The downside was committing to doing everything at once. A *rehosted-only environment* will not allow the current operational CRM solution to yield any new benefits. But adding the data warehousing vendor's integrated analytic CRM solution will produce some benefits through new capabilities, including event-based marketing.
- *Base Case 2: Rehosting and rearchitecting all data marts at once.* Compared to Base Case 1, this also involves developing a unified data model for all data marts and reengineering the data before they are migrated into the data warehouse. To the data warehousing vendor's project team, *rehosting and rearchitecting* all data marts simultaneously was an unrealistic strategic choice. Instead, rearchitecting data mart clusters that closely bind together and share common attributes (e.g., Clusters III and IV in Figure 3), in an appropriate sequence, was viewed as being capable of improving data quality and yielding higher CRM payoffs. However, no "stage-gate" reviews were to be included that would give flexibility to adjust the investment trajectory. As such, committing to a full rearchitecting effort was also viewed as adding to risk, though it would lower the vendor's professional IT services costs due to efficiency and scale economies. Moreover, it was viewed as adding nothing to the benefits of the current CRM solution. It was felt that rearchitecting would add much value only if an integrated CRM solution were deployed later.

Financial analysis indicates that the expected net present value (NPV) for both base cases is positive and significant. The expected NPV for Base Case 1 is $551,685 and
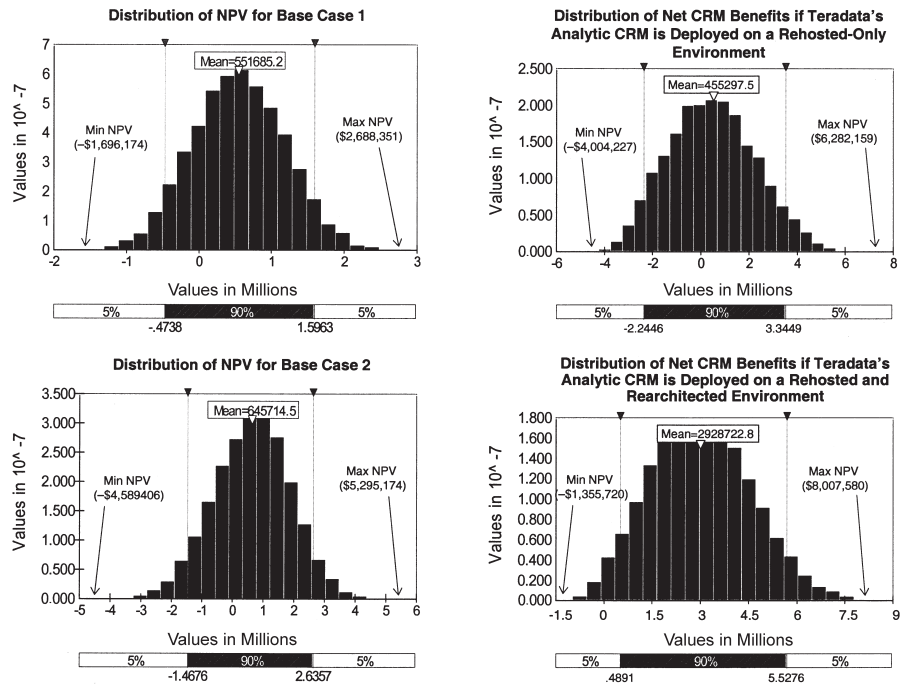
Figure 4. NPV Distributions for the Base Cases

for Base Case 2 it is $645,715. If the integrated CRM solution is added, the expected NPVs jump to $1,006,983 for Base Case 1 and to $3,574,488 for Base Case 2. Both are sufficiently high—in fact, one doubles the projected NPV while the other multiplies NPV by five—so that managers could appropriately make a "go" decision for each in isolation from the other. With the larger return on the combined rehosting and rearchitecting approach, though, this will be the preferred action.

Committing to full implementation despite uncertainty over the ability to realize expected benefits means that risk is high in both cases.[7] To better appreciate the issue of risk, we can look at the sensitivity analysis results for Step 7 (see Figure 1). These results are obtained by identifying the risk factors involved and using Monte Carlo simulations to examine their impact on expected outcomes. Figure 4 shows the NPV distributions derived for the base cases with and without the analytic CRM solution added. All distributions show significant variability, with internal rates of return (IRR) ranging between –60 percent and +90 percent as well as a 20 percent to 42 percent chance that the NPVs will be negative. The figures are encouraging only for Base Case 2 with the analytic CRM deployed, with IRR between –60 percent and +130 percent. This does not meet the high expectation executives have from an investment that could cost over $10 million and involve considerable organizational change [37].

We can improve on the base cases by adding flexibility to the investment to permit better management of risk. One configuration could involve a two-stage project. One data mart cluster would be consolidated in the first stage, after which a stage-gate

review would determine how much risk was resolved (e.g., extent of IT personnel reduction in actuality) and permit a better decision on whether to proceed with the remaining data mart clusters. This incremental approach creates a real option by requiring only a partial investment. However, the downside includes higher costs due to lost economies of scale and postponed cost savings. Other, more beneficial configurations are possible, pointing to the overall conclusion that the data mart consolidation investment should be configured to permit optimal management of risk and maximum value. The OBRiM framework answers this by identifying the real options (staging, pilot, abandon) to embed in the investment.

Step 3: Risk Analysis

OBRiM identifies *risk factors* or traits of the investment or its environment that can cause the project to stray from the planned trajectory and expectations. Table 2 shows OBRiM's generic IT investment risk factors (second column) and the related risk factors for data mart consolidation projects (third column).

The risk factors that we found to be relevant at our field study research sites are poor-quality data, low end-user participation, lack of senior management support, changes in end-user skill requirements, and slow user adoption [53]. There are other possible risk factors that were not explicitly mentioned by the data warehousing vendor's staff. They include lack of enterprise data warehousing skills and experience, the complexity of doing any rehosting or rearchitecting development on a "big bang" basis, high end-user utilization, and lack of technology for development [53]. Figure 5 shows an influence diagram tracing back from three outcome variables—implementation cost, immediate payoffs from data mart consolidation, and future CRM benefits—to uncertain input variables corresponding to OBRiM's IT risk factors.

Step 4: Identifying Real Options to Embed

In Table 2 in the right columns, we apply a subset of OBRiM's risk option mappings to the data mart consolidation risks identified for the airline firm. Each of the table entries can be thought of as a *named action* or a *named strategy* that involves executing an option with the same name. Some of these options were purchased by the firm and are *explicit* (e.g., to learn more by constructing a pilot prototype). The cost of other options may be *implicit* (e.g., deferring implementation defers the benefits that are realized, reducing the discounted cash flow). In either case, the strategic decision involves executing an option, with implicit or explicit costs. This results in an *exercised option.* We also marked certain real options as *nonviable. Viability* was determined based on whether the necessary and sufficient conditions for the real option to exist [6] are met by the airline firm's investment assumptions. Some additional reasons for the risk option mappings are:

Table 2. Data Mart Consolidation Investment Risks and Their Mapping to Suitable Real Options

			Risk option mappings								
Risk area	Generic IT investment risks	DMC risk factors	Defer	Stage (stop–resume)	Prototype	Pilot	Exit (switch–use)	Contract	Outsource	Lease	Strategic growth
Project / technical	Staff lacks needed technical skills and experience	(1) Inadequate enterprise data warehouse skills and experience[1]	#	#	§				†	§	
	Project is too large or too complex	(2) One-shot rehosting and rearchitecting effort for multiple data marts is a very complex endeavor[1]		#	§	#		#	†	§	
	Inadequate infrastructure for implementation	(3) Poor quality of the data sources (could cause delays, technical problems, and added costs)		#		#	§				
Functionality	Wrong design (e.g., analysis failed to assess correct requirements)	(4) Low end-user participation provides IT team with inadequate requirements (and can lead to less successful rearchitecting)		#	§		§	#	†	§	
Organizational	Uncooperative internal parties	(5) Lack of management support and uncooperative IT personnel in the handling of IT personnel reduction (or displacement)	§	#	§	#	§				
	Parties slow to adopt the application	(6) Changes in skill requirements of end users relying on data marts, and poor retraining of end users		§		#	§	#			
		(7) Users slow to adopt new enterprise data warehouse capabilities (and CRM-enabled business processes) and incorporate them into their daily work		#		#	§	#			

Table 2. Continued

Risk area	Generic IT investment risks	DMC risk factors	Risk option mappings								
			Defer	Stage (stop–resume)	Prototype	Pilot	Exit (switch–use)	Contract	Outsource	Lease	Strategic growth
Environmental	Demand exceeds expectations (presenting follow-up opportunities that might not be acted upon)	(8) High end-user utilization of the new enterprise data warehouse capabilities could present follow-up opportunities in integrated CRM (and supply-chain management) that the organization may fail to realize[1]	§			#				§	#
Technological	Application may be infeasible with the technologies considered	(9) Inadequate development technology (hardware, software, methods)[1]		#	§		§		†	§	
		(10) Poor scalability of platform to future expansion[1]		#	§		§		†	§	

Source: Adapted from Benaroch [6].

Notes: # = viable option; § = nonviable option; † = viable option; [1] Correspond to risks that Global Airline already addressed via outsourcing and via the consideration of follow-up investment opportunities in CRM.
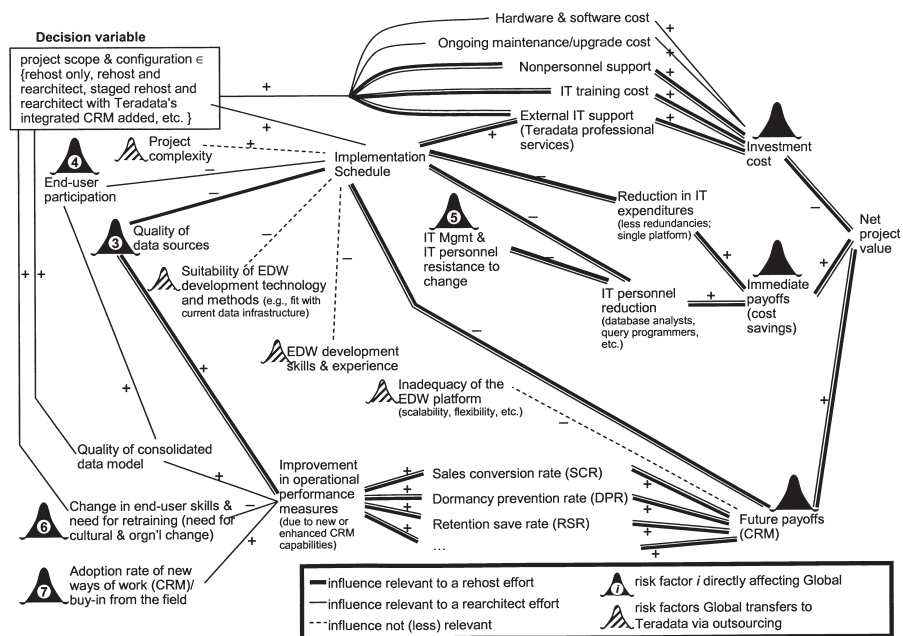
Figure 5. Influence Diagram for Global Airline's Data Mart Project

- The real option to *defer* the project or one of its parts is not viable. No new information that would help resolve any risk is expected to arrive over time in this particular setting.[8]
- The real option to *stage* (stop–resume) or to gradually consolidate data mart clusters is viable. It permits stopping implementation in midstream.
- The real option to *prototype* aspects of the project is not viable. For consolidation of data marts to be effective, it must create a fully working enterprise data warehouse.
- The real option to *pilot* the project on a small scale is viable. This is a variation of the stage option that involves only a pilot stage and full-scale follow-up implementation stage.
- The real option to *exit* (switch–use) during implementation or after the enterprise data warehouse becomes operational is not viable. No project resources can be released for more valuable uses.
- The real option to *change scale* only allows reducing the project scope (fewer data marts, no rearchitecting). The initial project scope already covers all data mart clusters the airline firm is seeking to consolidate.
- The real option to *lease* implementation hardware and software resources is not viable. Once a data mart is consolidated, only the finished product is available.
- The real option to *outsource* implementation is viable but already exercised. The airline firm has already decided to outsource the project, in part, to transfer risks to the data warehousing vendor. These arise from the airline's lack of data

mart development skills and enterprise data warehousing development methods. Another reason is the project's complexity.

- One *growth* option is a follow-on investment in an integrated analytic CRM solution. It is viable if the high end-user utilization materializes.

Step 5: Choosing Investment Configurations

This step designs investment configurations using subsets of the viable real options identified (pilot, stage, contract, and growth). Many different investment configurations can be designed, but the number of configurations worth considering is much smaller. Here, a good understanding of the business environment helps to rule out many implausible or inferior configurations before any quantitative valuation is conducted.

In the airline firm's case, the configurations we designed are governed by context-related assumptions and other assumptions about the viable options and their combinations. Some illustrations follow:

- If the data mart consolidation project is to be staged, each stage would include the data marts in at least one cluster.
- Independent of which configuration is pursued, if an integrated analytic CRM is used, its implementation would occur immediately after.
- If the project is staged, the rearchitecting of data mart Clusters III and IV would be bundled together—even if cost savings get delayed.
- The data mart consolidation *staging* option permits midstream *shutdown,* without affecting existing or consolidated data marts.
- The option to *pilot* involves consolidating *m* out of *n* data marts ($m < n$). This could be followed by a one-shot consolidation of the remaining *n–m* data marts.
- For the *stage* and *pilot* options, the airline firm can incrementally acquire hardware and software resources via enterprise data warehouse "nodes" [42, 43].
- The option to *contract* is viable only in combination with the *stage* and *pilot* options. With the *stage* option, contraction would limit data mart consolidation to only rehosting. With the *pilot* option, contraction would limit the full-scale implementation stage to only rehosting or to fewer data marts.
- The *growth* option includes only the integrated analytic CRM prospect, whose deployment has a higher value on a rearchitected environment.

Step 6: Real Options Valuation

We next calculate the *active NPV* for each investment configuration, to find the one that maximizes value. This requires computing for each configuration the value that embedded real options add to the *passive NPV*. For this field study of the data warehousing vendor and the airline firm, we use a *multi-option nested binomial pricing model* that Benaroch et al. [10] adapted to fit traits of the options involved. These traits are as follows. Each real option has an underlying asset equaling the incremental cash flows plus the future options its exercise generates. The real options are sequen-

tial and do not overlap in time, as may be expected in most real-world sequential IT investment projects. The real options are European because of budget cycle issues. The parameters the model requires are the underlying asset value, the exercise price, time to maturity, and the volatility of the underlying asset. The first three are estimated based on data used for the base cases. Estimating volatility requires additional work, which we discuss next.

An important question remains though: What leads us to believe that these models can capture firm-specific valuations? The answer we seek to verify is that the value of real options is determined by both the model and the parameters that the model uses. There are three elements to this argument—two relate to risk estimation and the last relates to estimation of growth options. First, the way risk factors are (and should be) estimated must reflect firm-specific perceptions of those risks. If two firms estimate risks differently, then the option valuations will be different. On this premise, one of our subgoals is to determine how doable it is to develop firm-specific risk estimates. This issue can be linked to the risk estimation challenge we discuss a little later. In particular, for the airline firm's IT investment, some risk factors were estimated subjectively by the firm's executives, whereas others were estimated based on external benchmarks from the data warehousing vendor.

Subjective estimates are more consistent with firm-specific valuations, but they are subject to biases. Estimates based on the vendor's benchmarks are less subjective, but they move away from firm-specific valuations. We know how this works in practice from other research on computer-aided software engineering that we conducted in the past [3, 4]. Similar issues arose with respect to estimates of the cost of building large-scale infrastructure systems for investment banking and brokerage services. In general, two different customers who are involved in consulting with an outsourcing vendor are likely to end up with valuations that are formulated on a similar basis, due to the high one-time cost of building a baseline model to support further analysis work. At the same time, benchmark-based estimates are likely to be more reliable and less biased than subjective estimates, and are subject to improvements over time with use and experience on the part of the vendor.

Another parameter we feed into conventional option valuation models is the risk-free interest rate, and it plays a role in firm-specific project valuation in many investment contexts. We know this is problematic because it is geared toward market-driven, not firm-specific, valuations. The risk-free rate, for example, fails to capture the degree of firm-specific risk, as does weighted average cost of capital. The latter calibrates project risk relative to the next dollar of project investment for the firm as a whole, rather than for the project in isolation.

A final parameter used in conventional option valuation models is the estimation of soft benefits and growth options—two additional considerations that will affect firm-specific valuations. It is interesting in this context to see the extent to which the "digital options for IT strategy" message has been picked up by the business press and business school faculty [38]. In spite of the attention given to these ideas, and the emphasis that has been placed on the "reconceptualization" of the role of IT resources, there still is no foolproof approach to valuing IT and organizational flexibility

in relation to future contingent strategies. As far as we can tell, most authors in the literature view this as being in the realm of subjective evaluation by managers, and, for that reason, they do not tend to challenge it or dwell on it (e.g., [7, 8, 13, 14, 18]). Instead, the main point of view that has been expressed is related to the appropriateness of the conceptual thinking that goes along with firm-specific valuation via real options, and the intuition associated with valuation under uncertainty with information revelation occurring over time. In contrast, however, the estimation of volatility for real option–related cash flows seems much better understood, including in ways that rely upon historical information to calibrate them.

Volatility Estimation

We estimated the volatility for each individual real option i in data mart consolidation configuration j corresponding to a specific consolidation stage (which generates its own incremental cash flows), $\sigma_{i,j}^{DMC}$. We did the same for the growth option corresponding to CRM deployment in configuration j, σ_j^{CRM}. *Volatility* here may be seen as the aggregate contribution of every risk factor to the variability of cash flows, assuming uncorrelated risk factors.

We estimated $\sigma_{i,j}^{DMC}$ by running Monte Carlo simulations for each real option in each configuration. The risk factors contributing to $\sigma_{i,j}^{DMC}$ are IT management and IT personnel resistance, quality of data sources, and end-user participation (see Figure 5). Because IT management and IT personnel resistance influence only IT personnel reduction, their impact on volatility is directly reflected in the distribution of the latter. Brainstorming sessions with managers were revealing. They believed IT personnel reduction would follow a normal probability distribution. This resulted in the mean and variance parameters of the distribution for the staffing requirements for a consolidated enterprise data warehouse. They agreed to truncate the distribution because they knew there would be minimum and maximum IT personnel reductions.

Both quality of data sources and user participation directly influence implementation schedule. Volatility due to quality of data sources was estimated based on a proprietary scheme from the data warehousing vendor. This variable is normally distributed, with the distribution parameters depending on data mart age, platforms used (Oracle, IBM, etc.), the number of IT staff operating them, and the types of interfaces with applications they serve, among others. The variability of end-user participation during rearchitecting is also assumed to be normally distributed. It is estimated using a proprietary tool that the data warehousing vendor uses to measure its client's *degree of customer-centricity*. (We elaborate on this below.) Given the normal distributions of these variables, we assume a linear and additive relationship between them and the implementation schedule variable.

To estimate σ_j^{DMC}, also with a Monte Carlo simulation, we consider how the data warehousing vendor uses a key metric for the client. The degree of customer-centricity is a predictor of three risk factors affecting CRM implementation: end-user participation, which also affects rearchitecting; cultural, organizational, and end-user skill changes affecting customer-facing employees; and end-user adoption. A *base degree*

of customer-centricity case for a client is developed by assessing its current CRM practices along three dimensions—profiling and segmentation, critical event management, and retention and loyalty programs. Customer-centricity on each dimension is measured using a five-level scale—foundation, intermediate, advanced, leading edge, and breakthrough. This assessment shows "where the client is" and "where the client could go" with an integrated analytic CRM solution. Our field study interviews suggested that the airline firm was in the "intermediate" level for "profiling and segmentation" and "retention and loyalty," and in the "foundation" level for "critical event management."

Based on the performance improvement experienced by a benchmark set of clients who already adopted the data warehousing vendor's analytic CRM solution, the variance of the airline firm's improvement potential was estimated with operational business performance measures. Those included *sales conversion rate* (SCR), *retention save rate* (RSR), and *dormancy prevention rate* (DPR), among others. Consider the case of sales conversion, SCR. Because the company was assessed as being in the "intermediate" level for "profiling and segmentation" and in the "foundation" level for "critical event management," potential improvement in the SCR is estimated to be in the 50 percent to 100 percent range. The 50 percent lower bound is the potential improvement yielded by moving from the "foundation" level to the "intermediate" level on "critical event management." The 100 percent upper bound is the potential improvement yielded by moving from the "intermediate" level to the "advanced" level on "profiling and segmentation." With SCR having a 50 to 100 percent improvement range, and assuming a normal distribution with a mean of 75 percent, the implied volatility of CRM benefits due only to an uncertain improvement in SCR is 33 percent. It also is possible to estimate the variability of potential improvements on all relevant operational performance measures (RSR, DPR, etc.). We estimated σ_j^{DMC} using a Monte Carlo simulation that assumes a linear and additive relationship over all factors influencing CRM payoffs. The weighting of operational performance measures is relative to the financial impact that a 1 percent improvement in each measure would have on CRM payoffs. For example, to calculate the financial impact of a 1 percent operational improvement in SCR, we can use the number of new annual conversions, the net annual dollar contributions per converted lead, and the number of times customers are contacted in a year.

Evaluation Results

Figure 6 summarizes the valuation results for 15 data mart consolidation configurations, denoted C1 to C15. The base case configurations are labeled C1/B1, C4/B1′, C8/B2, and C10/B2′. C13 has the highest active NPV, so its staged implementation strategy is best for managing risk.

C1 to C7 have low valuations because they involve only rehosting and the CRM benefits are low without rearchitecting. Yet real OBRiM still adds value, especially in C5. But notice that compared to C1/B1, which has no embedded real options, C2 and C3 have a lower passive NPV. This is because staging and piloting increase the cost of rehosting, but their risk management approach adds real option value that increases
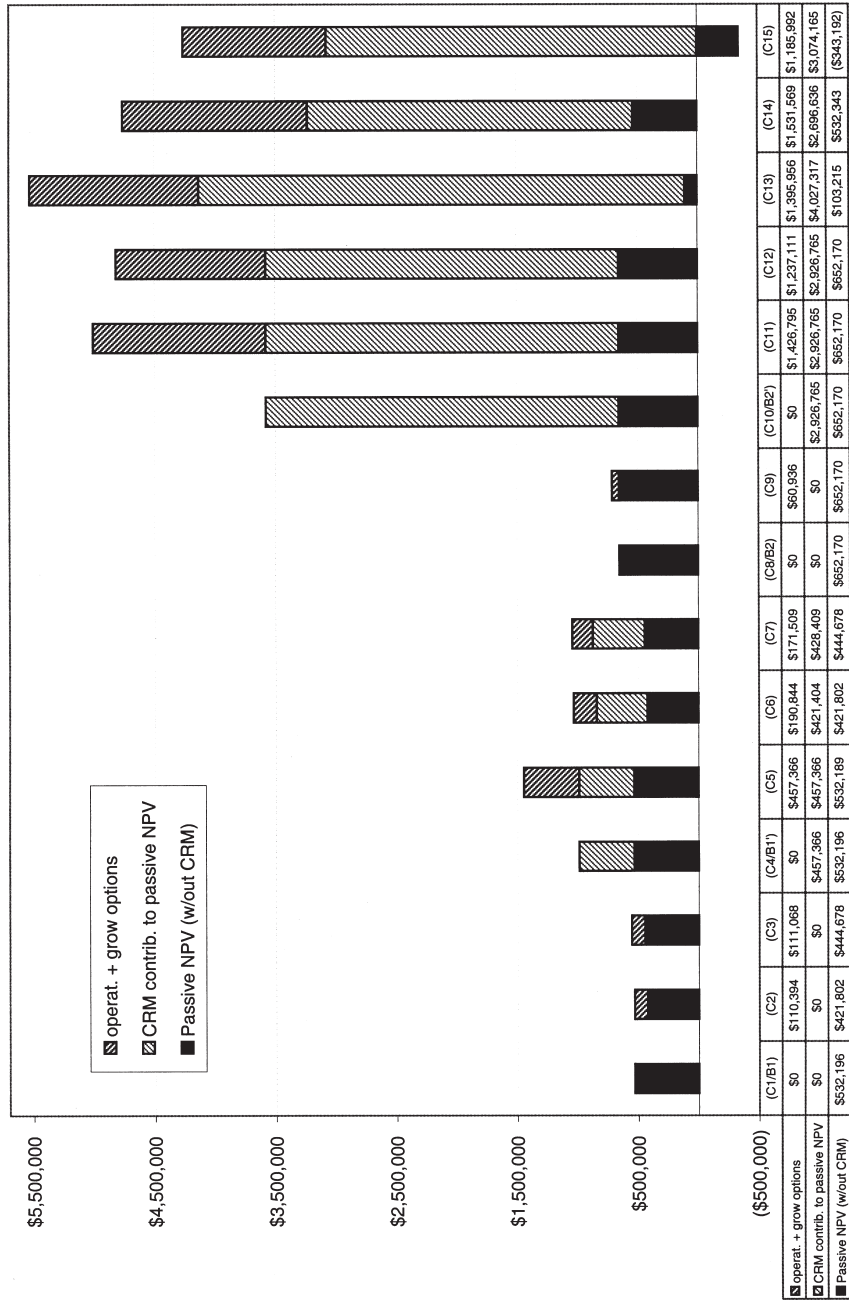
	(C1/B1)	(C2)	(C3)	(C4/B1')	(C5)	(C6)	(C7)	(C8/B2)	(C9)	(C10/B2')	(C11)	(C12)	(C13)	(C14)	(C15)
operat. + grow options	$0	$110,394	$111,068	$0	$457,366	$190,844	$171,509	$0	$60,936	$0	$1,426,795	$1,237,111	$1,395,956	$1,531,569	$1,185,992
CRM contrib. to passive NPV	$0	$0	$0	$457,366	$457,366	$421,404	$428,409	$0	$0	$2,926,765	$2,926,765	$2,926,765	$4,027,317	$2,696,636	$3,074,165
Passive NPV (w/out CRM)	$532,196	$421,802	$444,678	$532,196	$532,189	$421,802	$444,678	$652,170	$652,170	$652,170	$652,170	$652,170	$103,215	$532,343	($343,192)

Figure 6. Comparison Values of 15 Investment Configurations for Global Airline's Data Mart Consolidation

active NPV. Piloting is more beneficial than staging because it does not increase the cost of rehosting by as much. Compared to C4/B1′, which has no embedded real options, CRM deployment in C5–C7 is contingent on the success of rehosting. This adds a small option premium that makes C5–C7's active NPV even higher. Interestingly, although C6 and C7 use staging and piloting options to manage risk, their active NPV is lower than C5's. They both postpone the data mart consolidation savings and increase the cost of rehosting by more than the value that their real options add. Why? Because the real options involved resolve only one risk in CRM implementation—data source quality.

Configurations C8–C15 also involve rearchitecting, but only C10–C15 have much higher valuations because they consider deployment of an integrated analytic CRM. C10/B2′ has a much higher value than C8/B2 and C9, for example. (Configurations C8/B2 and C9 have the same passive NPV: they rearchitect data mart clusters in the same order, but C9 permits staged commitment.) Still, other configurations that use real options to manage risk have as much as 50 percent more value than C10/B2′. For example, contingent investment for CRM deployment in C11 adds option value of about $1.5 million. Generally, when CRM deployment is contingent on the outcome of rehost and rearchitect, the CRM growth option adds much more value.

Data mart consolidation, especially rearchitecting, permits resolving multiple CRM implementation risks. In this sense, the value of option-based risk management is more visible in C12, C13, C14, and C15, which also involve stagewise rehosting and rearchitecting with different stage sequencing. The passive NPV and active NPV for C14 are slightly lower than those in C12. This is another case where a higher cost of creating real options is due to delayed savings from consolidation, higher implementation costs, and delayed CRM improvements. C13 has a lower passive NPV than C12 and C14, but it has the highest active NPV. C13 leads to less cost savings from consolidation. Its sequence for rehosting and rearchitecting, however, permits resolution of the maximum CRM risk. This is also evident from the lower volatility of CRM benefits that Monte Carlo simulations produced for C13. Its sequence also yields higher CRM benefits due to better overall data quality. For C15, its passive NPV is negative because the implementation cost structure is high, and its active NPV is worse than even the nonstaged C11. This case contrasts with the pilot rehost and contingent CRM deployment in C7, which is superior to staged and nonstaged rehosting with contingent CRM deployment in C5 and C6.[9]

OBRiM: Field Study Assessment and Implications

WE NOW MOVE INTO A DISCUSSION THAT PROVIDES a critical assessment of the OBRiM framework based on our field study evaluation. To balance the assessment against current managerial practices, we interviewed two of the data warehousing vendor's senior executives about the practical value of OBRiM: Todd Walter, Chief Technical Officer, and Cheik Daddah, Director of the Business Impact Modeling team.

OBRiM's Overall Strengths

The managers and staff in our field study reported a successful application of OBRiM in their business setting, although some simplifying assumptions were made along the way.[10] The results obtained for Global Airline show how real options can be used to manage risk and optimize value in the context of enterprisewide data mart consolidation and enterprise data warehousing projects. Two other findings emerged. First, OBRiM produces investment configurations that add significant value. As we see in Figure 6, C11–C15 yield dramatically higher valuations because of the flexibility that the real options provide and the substantial CRM payoffs in a rearchitected environment; this is so especially because the real options permit resolving risks that affect both the rearchitecting effort and CRM deployment. Second, some of the investment configurations that OBRiM produces may result in loss of value. For example, configurations C6 and C7 have earlier project stages that do not permit resolving sufficient risk, in which case the cost of creating managerial flexibility from using real options outweighs their value.

The executives found OBRiM to be logical and have four main benefits—more accuracy in risk analysis, greater rigor, support of proactive planning, and correspondence with the real-world observations:

> [The OBRiM framework is] a really valuable way for us to codify what we've been trying to tell people; that there are a lot of choices and there are different risks, rewards, and cost components to the equation for each choice. (Todd Walter)

> I think more importantly [one of the] lessons learned is that [OBRiM] applied a lot of rigor to this with real options. You've looked at every scenario . . . when it comes to consolidation, and your conclusions are in sync with what the observers in general and Teradata, in particular, are seeing out there, which gives a tremendous credential and credence to this approach. (Cheik Daddah)

The conceptual and technical complexity of real options analysis has been often seen as an obstacle to their use [44], but the interviewees suggested this was not so—at least in this evaluative illustration:

> This approach is a good marriage of theory and practice. I really like the various options you have defined and the risk areas [you've identified] not just for enterprise data warehousing but also for consolidation. I think what's important [is that] [OBRiM] simplifies the complexities of options and the different strategies that you can pursue, but in a clear way. (Cheik Daddah)

So what emerges is that an important strength of the OBRiM framework is its ability to bridge related but largely disconnected research streams on real options. One stream involves people trained in finance and economics, whose main focus is on technical aspects of valuing investments using real option models. This stream is high on rigor, but often does not capture the complexities and nuances of applying options to effectively represent real-world IT projects. The other stream tends to be more strategy

focused, and is more concerned with using the real options logic to articulate managerial heuristics and reasoning processes. This stream recognizes the complexities of applying real options in practice, but it typically does not offer a rigorous approach to finding an optimal structure for configuring the various real options that could be embedded in projects. The airline company illustration demonstrates how OBRiM supports blending the strengths of both research streams in a context that reflects the real-world complexities of IT investment management.

OBRiM's Challenges

Applying OBRiM is not without issues. Many of the challenges that we identified in this research also relate to common capital budgeting techniques such as NPV analysis. In particular, the problems relating to risk identification and risk estimation are crucial to every meaningful form of sensitivity analysis (e.g., Monte Carlo simulation), independent of whether OBRiM is used.

Risk Estimation

An important set of issues we faced relates to the estimation of risk factors. These issues link to the estimation of volatilities for real options, a task often claimed to be a challenge in applying the real options body of knowledge.

For the airline's investment in data mart consolidation, we estimated the volatilities for real options based on the standard deviation of the logarithmic annual returns associated with outcome variables (i.e., immediate cost savings, future CRM benefits) representing assets underlying the real options [16]. These returns are defined by

$$z = \ln\left(\frac{PV_{t+1} + FCF_{t+1}}{E\left(PV_t\right)}\right).$$

The numerator is the free cash flows, *FCF*, in time period $t + 1$ plus the present value, *PV*, in period $t + 1$ of the cash flows starting in period $t + 2$. The numerator changes as uncertain input variables representing risk factors in the underlying financial model vary (see Figure 5). The denominator $E(PV_t)$ is the expected present value of the cash flow starting in period t based on today's information about the expected values of uncertain variables. The denominator stays the same throughout the simulation iterations. Monte Carlo simulations of z used @Risk software deployed on an Excel spreadsheet containing the financial model, where the distributions of uncertain input variables were anchored in subjective estimates from the airline's managers as well as in benchmark metrics from the data warehousing vendor.

This estimation approach raises several questions. In particular, why rely on subjective estimates of risk despite human cognitive biases and agency issues? And are there drawbacks to relying on the data warehousing firm's benchmark metrics (e.g., using "customer-centricity" as a proxy for other risk factors) in this context?

Practitioners often resort to subjective risk estimates in the lack of adequate alternatives. Only recently has IT research started looking at IT investment risk [13, 15] and

its measurement challenges (e.g., [26]). Dewan et al. explain: "There is a great need for . . . understanding . . . the observed risk–return profile of the different classes of IT investment. [This] would go a long way to help executives manage their IT investment portfolios more effectively" [18, p. 21]. The challenge lies in developing operational measures for risks that can be related to IT investment returns and in having suitable data. Estimation of risk could be based on firm-specific data, benchmark data, or public market data. In this field study, because the airline firm lacked firm-specific data relevant to risk estimation, we sought to lessen reliance on subjective estimates to the extent possible by using benchmark data about many of the data warehousing vendor's clients. Considering that the firm's staff and managers felt satisfied with our risk estimates and the valuations they enabled, our reliance on benchmark data in this study does not seem problematic.[11]

An important research issue remains open though: It is not clear what is the right approach to generating reliable firm-specific valuations of option-bearing investment structure. Is it better to use valuation models that do not impose strong assumptions on the contextual settings but produce valuations that hinge on subjective and possibly biased risk estimates? Or, is it better to rely on financial option models that impose strong assumptions but can accept and work with more reliable benchmark- and market-driven risk estimates? The answer must consider the trade-offs between the two views more systematically.

Risk Identification and Mapping to Options

A related issue pertains to limiting our risk analysis to OBRiM's generic IT investment risks. We used an influence diagram to trace back from outcome variables to risk factors in OBRiM's list. This decision-theoretic approach is typically used for base case analysis and sensitivity analysis. More detailed risk classifications, such as Schmidt et al. [39], identify over 70 different risk factors and bring up questions on granularity and completeness of OBRiM's risks list. For the airline firm, using an outsourcing real option to control certain risks may introduce new risks, including contractual risk and communication risk [52]. This would require reapplying OBRiM's steps to the potential risks of outsourcing, but OBRiM's risks do not cover that.

A basic research question motivated by this is: What taxonomy of IT risks is reasonably complete and at a level of granularity that is adequate for risk identification and estimation? The answer must consider the risk option mappings OBRiM uses to prescribe which real options to embed for specific risks. If OBRiM's list of risks is to be refined, can its risk option mappings be made more granular? If so, how?

Designing Investment Configurations

We said earlier that one of the perceived strengths of OBRiM is that it enables managers to generate alternative investment structures. However, as we saw for the data mart consolidation project, the number of alternative investment configurations designed using real options may be large. A further challenge we faced—also noted by the senior

executives—is the effort that many configurations entails. The number of investment configurations can be reduced by designing hybrid configurations. For example, depending on what a *pilot* data mart consolidation effort reveals, we could proceed with a full-scale rehost and rearchitect effort, *contract* this effort to only rehosting, or not proceed with DMC at all. This approach produces fewer configurations, but the configurations are more complex to construct, explain, and evaluate.[12]

We chose to look only at simple configurations that are easy to design, comprehend, and evaluate. For this approach to work well, it would be ideal to develop decision support tools that can assist in screening out inferior configurations, computing option values, and so on. Such tools would require automating some technical details of OBRiM and developing heuristics for picking promising configurations. Still the basic questions remaining are two: How do we go about reducing complexity due to a multitude of alternative investment configurations? And, are managers better off generating on their own alternatives they find most deserving of their attention? The answer requires empirical consideration of decision makers' preferences, cognitive biases and limitations, and prior experience with real options [25, 41].

A related issue is the feasibility of conducting sensitivity analysis. We were hoping to provide managers with sensitivity analysis information that would enable them to see the effect of option-bearing investment structures on the ability to control risk. However, this turned out to be infeasible with Monte Carlo simulations. A difficulty is the need for nested simulation runs—an inner one for estimating volatilities for embedded options, and an outer one for estimating the probability distribution of the active NPV. Current software tools such as @Risk do not support nested simulations. Hence, the following open question emerged from our study: What is a good approach for conducting sensitivity analysis for investment structures that embed complex combinations of real options?

Growth Options and Soft Benefits

Research studying the business impact of IT investment has shown the importance of growth options [19, 38]. OBRiM and real options analysis call for the identification and valuation of growth options [17]. Still, an important question is: Which growth options should be considered when looking at an IT investment opportunity?

The relevance of this question is apparent in the data mart consolidation project. The airline managers in our field study site identified CRM deployment as the only plausible follow-up investment. It overlooked other enterprise data warehouse–enabled opportunities such as supply-chain optimization and business intelligence. The decision to consider only CRM was influenced by the airline's focus on CRM and, we suspect, by the data warehousing firm being cautious not to oversell the business value of an enterprise data warehouse in terms of growth options. Of course, the risk of taking too cautious an approach is one of undervaluation and underinvestment.

This leaves us with the question: What is an adequate approach to determining which growth options to consider for a specific IT investment? It is interesting to mention an approach that was used in the past. Research applying real option analysis

in one pharmaceutical company has found, based on documentation of past R&D projects, that each project has, on average, spawned nearly two follow-on investment opportunities that were eventually pursued [35]. How applicable is this approach to IT investments? Can we develop benchmarks for different types of IT investments, organizations, or industries?

Interpretation and Action on OBRiM Results

Interpreting the results of OBRiM and deciding how to act on them is another issue that needs to be given closer attention. The challenge is when two not necessarily compatible perspectives are involved, as in the case of outsourcing. From the perspective of the airline firm, since one configuration (C13) is best to pursue, it should structure a flexible outsourcing contract that embeds contingencies for breaking the contract in midstream. If the airline chooses to pursue a staged strategy, the data warehousing vendor should require provisions in the outsourcing contract to reflect possible contact cancellation in midstream. For example, the vendor firm might prefer a risk-sharing, value-based contract to extract a higher fraction of returns from the airline. The reality though is that few client firms would agree to a value-based contract, although some research is already noting the plausibility of this [34].

In this light, a remaining challenge for the data warehousing vendor and the airline firm is how to use the OBRiM results to reach a value split that is fair to both. Irrespective of which data mart consolidation project configuration the airline decides to pursue and how the outsourcing contact is structured, the project would have to be reevaluated after each stage is completed. Then, depending on how much risk a completed stage resolves, the airline firm still would need to decide which real option(s) to exercise. It may also be necessary to determine how to readjust its data mart consolidation investment configuration over time.

This brings up the issue of exercising real options. The relevance of this is apparent from another comment offered by one of the senior executives we interviewed:

> Many managers build decision points into their projects, but I see way too many who get to the place where they should cancel the project [e.g., exercise an abandonment option] but don't. If you have a tool like [OBRiM] that shows the long-term cost, and the long-term downside risk of not taking the option, then I think that has a lot of value. (Todd Walter)

Other research suggests that organizational and cultural biases can cause managers *not* to exercise real options when it is necessary to exercise them [21, 29]. The influence of such biases can be greatly reduced if managers see the cost of not exercising real options from a rational economic perspective. Although OBRiM does show the value that real options add if they are exercised when appropriate, it does not explicitly show the monetary consequences of not exercising these options when warranted. This *opportunity cost of inaction* needs to be explored further.

OBRiM Adoption Challenges

The challenges discussed above suggest some of the complexities that could impact OBRiM adoption by organizations. This concern was expressed by the senior executives we interviewed:

> It's all about the maturity of the organization. . . . If you don't have people in the organization that can lay out the decision trees and do the financial analysis, then none of this works. There are still way too many organizations out there that don't have the maturity to do this. (Todd Walter)

> As far as implementing this [OBRiM] in front of customers, I can tell you that probably there may be one or two customers who have people who are not only exceptionally bright but who have done some digging into this and could potentially see value in the quantification piece. I think there are certain pockets within certain organizations that this approach would have a more financial fit; if you look at banking, or the risk area in banking, because they use futures and options and they could look at stochastic and non-stochastic models et cetera for their data business, for example. The other area I could see is manufacturing where they have done a lot of six sigma-type implementations. (Cheik Daddah)

Two additional recommendations surfaced from the interviews for increasing the acceptance of OBRiM. One is clear: improving the training of IT decision makers in financial concepts is critically important. As managers develop a better understanding of, and gain more experience with, real options, OBRiM will become more useful to them. A similar recommendation came from a recent study on factors affecting the successful adoption of IT portfolio management practices [27]. The study found that 46 percent of 179 senior IT executives surveyed agreed that their IT staff members lacked working knowledge of important concepts from finance. Another recommendation is that OBRiM needs to be made more cost-effective in terms of its application time and the associated effort. Research on the challenges we discussed would go a long way toward developing methodological and decision support aids that could greatly simplify the use of OBRiM.

In summary, weighing OBRiM's strengths against its weaknesses, the OBRiM framework appears to be a valuable tool that has the potential to help managers to systematically structure large enterprise investments for the purpose of balancing risk and return:

> Any tools we can get that keep people focused on the long-term strategic value are good tools. Where I think [OBRiM] fits is that it allows people to look at that long-term strategic value and be able to quantify and even feel that they can control the risk, which, in many cases, seems or feels overwhelming. (Todd Walter)

OBRiM's application is not limited to the evaluation-focused illustrative setting that we have discussed. Instead, its use can favorably impact the risk and return balance for any large IT investment. With this said, we have identified several areas where

additional research is needed to make OBRiM, or a simplified version of it, more usable and useful to managers in firm-specific settings. We encourage others to join us in gaining more experience in applying OBRiM to other settings, so we can become more confident in making broader assertions about the extent of it managerial usability and value in practice.

Conclusions

OPTIMIZING THE BALANCE BETWEEN RISK AND VALUE, and taking into account the cost of creating real options in sequential IT investments, requires innovations for structuring a meaningful and implementable analysis for senior managers. In this paper, we discussed and evaluated the application of theory and methods related to OBRiM, an option-based risk management framework [6]. This framework helps a decision maker to systematically identify the real options to embed in an IT investment in order to manage risk. It recognizes the difference between those options that are explicitly purchased (e.g., building a prototype) and those that are implicitly held (e.g., deferring investment). OBRiM also emphasizes an analytical process that is focused on assessing the active NPV of a project, based on the application of various financial models and methods to evaluate alternative configurations of IT investments. OBRiM's IT investment evaluation thinking draws upon new ideas from corporate finance and financial economics that are of increasing interest to IS researchers and industry practitioners. It also supplements existing approaches in the IS literature [13, 17, 20, 21, 27, 30] by further emphasizing the roles of systematic identification of real options, risk estimation, sensitivity analysis, and valuation, and the interplay between passive NPV and active NPV in technology investment settings. In addition to the application of real options models, the primary vehicle for the development of the results in this research is Monte Carlo simulation. It is applied for alternative IT investment configurations that OBRiM helps an analyst to identify.

This research applies a field study methodology. This involved primary data collection and interviews of senior managers at two organizations. The purpose of pursuing research in this particular context was that we believed it would be appropriate for assessing our new methodology for the management of sequential investments in IT. The context was a large-scale data mart consolidation project that was being evaluated by an airline firm, relative to the technical services offered by a data warehousing systems solution vendor. The methodology blends the technical aspects of valuing investments using real option models with a more strategy-focused perspective. It also provides a means to find an optimal structure for configuring the various real options that could be embedded in projects. We applied OBRiM to identify several specific classes of real options, including the implicit options of deferral and abandonment, and the explicit options of piloting and staging. The approach proved to be useful and revealing for staff members at the field study sites who were studying how to achieve an optimal configuration for their data mart consolidation project so that it would embed the most value-bearing real options.

The primary findings from this research are in three areas. First, there is significant value in the managerial analysis of IT investment projects for which it is possible to simultaneously evaluate alternative configurations of the sequential investments that are involved, as a means to optimize the sequence and to drive active NPV to its highest level. This corroborates the recent findings of Bardhan et al. [5], who pioneered an IT investment portfolio evaluation approach that also aids in identifying how IT investment sequences should be structured so as to maximize portfolio value. Second, the application of Monte Carlo analysis is of particular benefit to managers in developing intuition about the business value of the alternative structures for option-bearing sequential IT investments. Future research can explore the further use of Monte Carlo simulations to enable decision makers to see the impact of using real options on the distribution of active NPV.

Third, we also have learned that OBRiM is viewed by managers, on the whole, as a valuable aid in their decision-making process. Although there are still issues with the large number of real options and investment structures that the analysis generates, the sense that we heard expressed was that the systematic approach that OBRiM uses was beneficial nevertheless. Our work contrasts with the work of Clemons and Gu [13] in that they focus on call-type options that create strategic flexibility, whereas OBRiM is more concerned with using put-type options to create operational flexibility. The IT investment assessment process that we studied has greater complexity than what is normally discussed in textbooks on capital budgeting. This complexity is due to the need to evaluate different investment structures that permit future contingent investments, real option–based commitment adjustments, and the management of the project's value trajectory over time, as new information is received.

In closing, we believe that the methodology we have evaluated complements techniques and evaluative perspectives that already exist in the literature, including scenario analysis, structured NPV approaches, decision trees, and sequential decision analysis and dynamic programming. Our emphasis on the contrast between the estimation values of passive NPV and real option–driven active NPV—and our consideration of the range of alternative configurations of the IT investment structure—constitutes a unique perspective that deserves additional effort for further development.

In spite of these contributions, the reader should recognize that there still are limitations. Our field study interviews identified several appropriate areas for additional development effort to be made. They include addressing the reliance on subjective estimates of risk to characterize the real options associated with a strategic IT investment; finding a means, as with other financial economics and risk management evaluation techniques such as value-at-risk and RiskMetrics, to obtain reliable market data that might become recognized as widely accepted benchmarks for IT investment risk; further validating the appropriateness of OBRiM's current risk categories for which real options can be mapped in the analysis; and further addressing issues surrounding the identification and calibration of growth options and soft benefits.

Another recurring issue, and one that we have seen in other interorganizational IT investment settings, involves how the benefits are split between the partners in the kinds of partnered IT investments and evaluation settings we see here. The difficulty

arises with the noncontractibility of the outcomes in terms of how value is to be shared. This is the well-known *incomplete contracts problem* that has been treated in the IS literature by Clemons et al. [15] in buyer–supplier procurement settings, and by Han et al. [23] for financial risk management systems investments. This additional risk suggests that, in the presence of uncertainty about the split of value from the outcomes of large-scale IT investments, both the IT services and systems vendor and the investing firm are likely to underinvest relative to the level that would be observed for an integrated firm. This further suggests the need for future research that examines strategic IT investment evaluation in terms of the associated incentives for effort and information sharing to achieve optimal commitment levels.

Notes

1. Throughout this paper, we refer to the word *option* in two different senses—a distinction that will help this research to connect more effectively to the strategy *and* financial economics literatures on sequential technology investments. One use is in the *real option* sense of buying a right or purchasing something to be able to take a value-bearing action in the future that may not be possible otherwise. Clemons and Gu's [13] interpretation related to this is that investments can be made to preserve flexibility and to accelerate subsequent choices, without requiring an expensive full commitment. They aptly characterize this kind of real option-bearing IT investment as a *strategy-enabling partial investment,* and further recognize that such partial investments cost less than fully acquiring the necessary resources. The authors further comment: "Importantly, [partial investments] enable speed of action when the appropriate course of action can be determined and they allow delaying full spending on necessary investments until it is clear *which* investments are required. When future conditions become known and requirements become clear, contingent IT investments can . . . be made. Thus, the initial investments are properly viewed as strategic options, while completing the future contingent investments can best be seen as exercising the strategic options created by initial investments" [13, p. 14]. The second use of the term *option* is in the sense of things that managers can decide to do that do not require any initial purchases or decisions. They are simply available in the normal course of managerial decision making in response to changing environmental information (e.g., *waiting* to finance and start up a new project due to expectations of lower future interest rates, or

abandoning a pilot project whose resulting software application has gotten out of sync with the market's functionality requirements).

2. A *data mart* is a collection of databases built to help managers make strategic decisions about their businesses. In contrast, a data warehouse combines enterprisewide databases. Data marts are usually smaller and are associated with a specific business function or process. For example, a customer service department may collect customer service and complaints data, while the firm's product Web site may record click-stream data on what products customers viewed.

3. Teradata is a division of NCR and a provider of enterprise data warehousing and integrated analytic CRM infrastructure solutions and IT services.

4. Although some may view our approach as *action research,* in which the authors drove the outcomes as evaluation project participants, this was not the case. This research was undertaken as *field study research* involving *retrospective analysis,* as we have seen in the prior published works of Bardhan et al. [5], Benaroch and Kauffman [7, 8], Schwartz and Zozaya-Gorostiza [40], Taudes et al. [45], and others. The goal was to evaluate outcomes that have been observed involving past actions and managerial decisions, and then structuring evaluation approaches around them to see how the outcomes may have been best understood to shed light on the theories and methods that have been applied. We see such retrospective evaluative approaches in the *case study research* of Han et al. [23] with explanatory economic modeling, Hess and Kemerer [24] with theory-testing industry-level evaluation, Clemons et al. [15] with interorganizational analysis of buyer–supplier risks, and Wigand et al. [51] with the analysis of standards in the home mortgage industry.

5. We will not fully treat the criticism that real options analysis with financial models cannot produce firm-specific valuations. As with any methodology or theory, there are issues that arise in application. Sometimes progress comes from stretching the bounds of existing applications as a means to free up our thinking for next-step innovations. We nevertheless should point out that the essence of useful financial evaluation in managerial and strategy contexts is to assist decision making by means that seem appropriate. Clemons [12] has argued that approximation, order of magnitude valuation, and the identification of the most critical strategic options available to a firm often surpass the usefulness of technically correct estimates of value.

6. *Passive NPV* is the traditional NPV without consideration given to real options and flexibility. *Active NPV* is passive NPV + real option value that arises from a firm's operating and strategic options. For additional discussion of passive and active NPV, see Benaroch [6], Benaroch and Kauffman [7], and Trigeorgis [46].

7. This echoes comments from Clemons and Gu, who state that senior managers are "concerned with avoiding any unnecessary investments in technology infrastructure in support of market opportunities that do not arise. They are trading off the desire for speed ('we have no time to waste') with the desire for certainty before acting ('we have no resources to waste'). This requires a methodology for justifying investments in assets that will be required only under specific sets of conditions, and for enabling rapid deployment of these assets when they are required" [13, p. 12]. The authors aptly call these *contingent investments.*

8. We thank an anonymous reviewer who pointed out that this is not *generally* the case, which we agree is true. With the passage of time, firms become more informed of the value of data warehousing, of the installation cost of the data warehouse systems, and of the potential future revenues due to CRM integration. This suggests deferral could have significant value. We have qualified our statement here, in keeping with assertions of the data warehouse system vendor's staff about what they believed were the situational conditions present in the project investment environment.

9. We must note that these results may not be interpreted the same way when viewed from the conflicting perspectives of the outsourcing vendor and the purchaser of IT services. The revenues of one are the costs of the other.

10. Recall our earlier clarification about the decision to assume that the real option to *defer* the data mart consolidation project or one of its parts was viewed as not being viable. This is a simplifying assumption that could be relaxed in additional analysis. According to real option theory applied to project valuation, any additional flexibilities and strategic choices that can be made available will only serve to increase the expanded NPV.

11. Early in the study, we also considered using other methods involving market data. A recent study shows how market data can be used to estimate certain IT investment risks using a multifactor investment model and the event study methodology [2]. However, it was not clear if such sophisticated methods are needed or even adequate.

12. A direction worth exploring is the use of dynamic programming to find the best investment configuration enabled by a given set of options. A similar approach for smaller-scale problems is by Wang and de Neufville [47].

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Appendix: Data Mart Consolidation

Data Mart Proliferation

A COMMON PROBLEM WITHIN LARGE ENTERPRISES is the proliferation of data marts. If each interaction with a customer is logged in a separate data mart, for example, it is not possible to create a single view of the customer. A solution to this problem is to undertake a data mart consolidation (DMC) project. This usually produces a single enterprise data warehouse, an integrated and centralized repository of comprehensive and detailed historical data that supports multiple decision-making applications and user groups.

A Data Mart Consolidation Project

Figure A1 is a high-level schematic of a DMC project for five data marts. (The estimated costs and time durations are presented only for illustrative purposes and the choice of
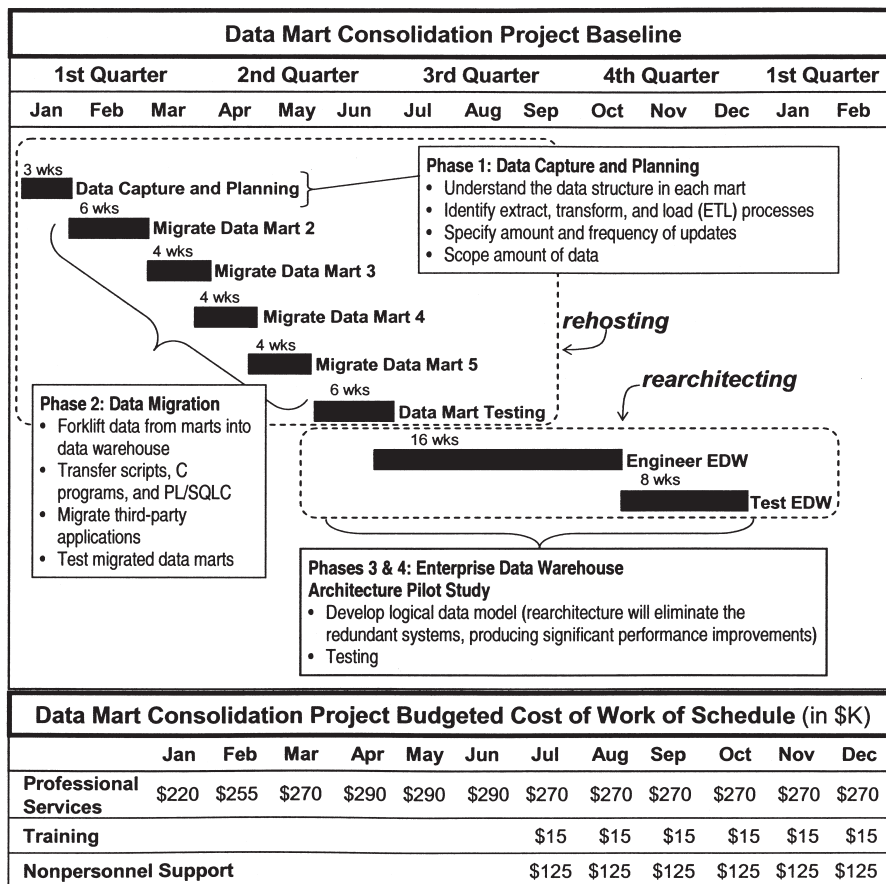
Data Mart Consolidation Project Baseline

1st Quarter			2nd Quarter			3rd Quarter			4th Quarter			1st Quarter	
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb

3 wks
Data Capture and Planning

6 wks
Migrate Data Mart 2

4 wks
Migrate Data Mart 3

4 wks
Migrate Data Mart 4

4 wks
Migrate Data Mart 5

6 wks
Data Mart Testing

rehosting

rearchitecting

16 wks
Engineer EDW

8 wks
Test EDW

Phase 1: Data Capture and Planning
- Understand the data structure in each mart
- Identify extract, transform, and load (ETL) processes
- Specify amount and frequency of updates
- Scope amount of data

Phase 2: Data Migration
- Forklift data from marts into data warehouse
- Transfer scripts, C programs, and PL/SQLC
- Migrate third-party applications
- Test migrated data marts

Phases 3 & 4: Enterprise Data Warehouse Architecture Pilot Study
- Develop logical data model (rearchitecture will eliminate the redundant systems, producing significant performance improvements)
- Testing

Data Mart Consolidation Project Budgeted Cost of Work of Schedule (in $K)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Professional Services	$220	$255	$270	$290	$290	$290	$270	$270	$270	$270	$270	$270
Training							$15	$15	$15	$15	$15	$15
Nonpersonnel Support							$125	$125	$125	$125	$125	$125

Figure A1. Data Mart Consolidation Projects

five data marts is arbitrary.) The project includes two main phases—rehosting and/or rearchitecting. *Rehosting* involves data capture and planning, then physical migration of the data, tables, and processes into the enterprise data warehouse, followed by a test and validation process. *Rearchitecting* involves the design of an integrated data model, the reengineering and update of data, and extensive testing of the resulting enterprise data warehouse. This phase can yield significant performance improvements by enabling a firm to harness the full value of integrated business data. Compared with rehosting alone, however, rearchitecting makes a DMC project more risky and adds 60–75 percent more time and cost [42, 43].

Data Mart Consolidation Benefits and Risks

Consolidating data marts into an enterprise data warehouse can offer significant benefits, but is subject to risk [37, 53]. Benefits range from immediate cost savings, to improved data analysis capabilities for day-to-day operations, to long-term follow-up

investment opportunities. Risks are attributed to business and organizational factors (e.g., management support, organizational politics, end-user involvement) as well as technical and technology factors (e.g., quality of data and systems, skills, tech maturity, and scalability).

Data Mart Implementation Outsourcing

Due to lack of experience, many organizations outsource their DMC implementations to an enterprise data warehouse vendor. Outsourcing the rehosting effort transfers to the vendor much of the technology and technical risk associated with the development team's skills and experience, development tools and processes, and adequacy of the technology platform. Outsourcing the rearchitecting effort lowers uncertainty over the user involvement needed to achieve an understanding of multiple database structures, formats, and platforms prior to the creation of an integrated data model. For many firms, 70–85 percent of the unified data model may come from industry models that enterprise data warehouse vendors have developed.

Actively Managing Data Mart Outsourcing Risk

Even if a DMC project is outsourced, the ability to manage risk is crucial, considering that DMC can cost from a few million dollars to several tens of millions. The challenge is threefold. First, it is difficult to balance trade-offs among the risks, costs, and potential benefits of a DMC project. The greater the scope of the project, the harder it is to manage the trade-offs. Second, some benefits are hard to quantify, especially for indirect payoffs from follow-up investments. Third, DMC projects are often structured on the basis of rules of thumb, not economic principles. One heuristic is to *stage* DMC for proof of concept to justify larger-scale investments.

Identifying Optimal Data Mart Consolidation Project Configurations

A consequence of these challenges is a dilemma that many organizations face: defining the scope of a DMC project. There could be many project configurations for defining the DMC scope. For example, the simplest is to rehost all data marts together. A little more complex approach is to rehost and rearchitect all data marts together. Still another level of complexity involves rehosting and rearchitecting several data marts at a time. An even higher level of complexity occurs with rehosting and rearchitecting data marts, and then following up with an investment in an integrated CRM solution. Even if the simplest configuration leads to a positive net financial outcome, more complex configurations may lead to better results. This is important considering that organizations are less and less open to accepting IT savings alone as a justification for a large DMC investment. They expect a DMC investment to fix a business problem. A fundamental economic question that many organizations face is: How to find an optimal DMC project configuration?