**Measuring and Managing Intellectual Capital in the U.S. Aerospace Industry**

by

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Submitted to the Department of Aeronautics and Astronautics and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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**ABSTRACT**

"Intellectual capital" has been heralded in business journals as an important component for successful business development in today's economy. Intellectual capital consists of knowledge-based assets – including people, relationships, tools, and processes – that create value for a firm and its clients. Previous research has emphasized the financial measurement of intellectual capital, including the valuation of corporate intangible assets and the difference between a firm's market value and book value. Unfortunately, these financial measures are not very useful to practitioners, as they provide few insights about how to allocate resources, improve operations, or strategically plan for future needs.

In this research, a new conceptual framework is developed for understanding the role of intellectual capital in new product development. The framework develops a dynamic model of the three forms of intellectual capital – human capital, structural capital, and relational capital – and identifies mechanisms for knowledge transfer, organizational learning, and value creation.

The framework is bolstered by data from case studies of seven product development projects at different U.S. aerospace firms. Using the concept of intellectual capital as a "lens", the case studies are comparatively analyzed to identify critical knowledge-based resources and capabilities that are used in the development of complex products and services. The studies suggest that a balanced portfolio of intellectual capital can create unique capabilities that lead to competitive advantage and differentiated performance. The analysis culminates in a self-assessment tool that managers can use to measure and assess the health of their intellectual capital base. In addition to providing management tools, the research has implications for U.S. aerospace policy, as well as the funding of further research into the role of corporate knowledge in today's information economy.

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# 1. Introduction

### *1.1. The Role of Knowledge-Based Assets*

In today's business environment, the maxim that "knowledge is power" has greater significance than ever before. As the global economy evolves towards being more information-intensive, a firm's knowledge-based assets are becoming more fundamental to its successful operation – that is, what a firm "knows" is often more important than what it owns.

Many pundits assert that this transformation represents a paradigm shift towards an information-based economy, heralding the arrival of the so-called "Information Age". Actions, however, speak louder than words: the truest indicators of this trend can be found in the activities of today's leading businesses. Companies are devoting increased attention to intellectual property rights and mining value from their portfolio of patents, copyrights, and trade secrets. Realizing the value of their corporate knowledge, firms continue to develop new tools, capabilities, and functional groups for managing knowledge within the firm. In knowledge-intensive industries such as biotechnology and pharmaceuticals, companies are plowing back larger portions of their revenues into R&D, in the search for tomorrow's profit-generating intellectual assets[1]. And corporate managers continue to search for ways to attract and retain the "best and the brightest" to foster innovation and fuel new product development.

In addition to developing in-house resources, companies today are also exploring how to strategically leverage their out-of-house relationships with suppliers, corporate partners, and clients to create value and boost profits. These relationships are based on intangibles[2], requiring managers to use their sector-specific knowledge to collaborate, coordinate, and combine capabilities to create mutually beneficial value propositions[3]. These intangible assets enable firms to re-evaluate which capabilities to keep in house; even in capital-intensive industries, firms are choosing to outsource more services and manufacturing capabilities[4]. As part of this "asset-light" strategy, physical assets that do not provide competitive advantage are treated as commodities, while the unique intellectual assets of the firm are retained. This trend underscores the strategic importance of knowledge that extends outside of the factory wall – and the value

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[1] Based on December, 2001 Corporate R&D Scorecard, *MIT Technology Review*, v.104, no.10, 2001. Additional research by Hall and Griliches suggests a positive correlation between R&D investments and corporate profitability; see Hall, B. "Industrial Research during the 1980s: Did the Rate of Return Fall?, BPEA:Microeconomics, 1993, and Griliches, Z., "R&D and Productivity:Economic Results and Measurement Issues", Handbook of the Economics of Innovation and Technical Change, Blackwell, 1995.

[2] The importance of intangibles assets was underscored in Itami, H., *Mobilizing Invisible Assets*, Harvard U. Press, 1987. Also see Lev, B., *Intangibles*, Brookings Institution, 2001, for a comprehensive survey on intangible assets and relevant research in this area.

[3] See Earll Murman, et al., *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*, Palgrave Press, 2002, for more on the importance of value identification and the value proposition.

[4] Outsourcing trends and their estimated contribution to GDP are summarized in "Out of the Back Room", *The Economist*, December 1, 2001, and Byron G Auguste et.al., "The Other Side of Outsourcing", *McKinsey Quarterly*, 2002 Number 1.

that companies derive from managing their supply chain, entering into joint ventures, and forming strategic alliances.

This emphasis on corporate knowledge – including both assets within the firm and those derived from its external relationships – has led to an increased awareness of the concept of "intellectual capital". Intellectual capital (IC) consists of the knowledge embodied in the firm's personnel, in the capabilities of the organization, and in the relationships of the firm with its clients, partners, and suppliers. Intellectual capital includes the value of corporate experience that is embodied in a firm's processes, procedures, tools, and organizational structures. Also included in this definition is intellectual property, information stored in knowledge management systems, and knowledge management efforts that seek to extract value from the firm's knowledge assets. Importantly, if we view these types of corporate knowledge as intangible assets, then intellectual capital has the potential to be managed and used to create value in ways similar to tangible assets. This is especially true for new product development, as firms try to create innovative products and leverage their knowledge base to generate new profits.

The increased awareness of intellectual capital and the importance of knowledge-based assets can be regarded as a two-edged sword. On the positive side, these intellectual assets – what a firm "knows" – represents a resource that is unique, discrete, built over long periods of time, and is often difficult to imitate. In theory, managers can use their unique combination of staff know-how, corporate processes, and relationships to create resources and capabilities that provide a competitive advantage over other firms. Since these capabilities cannot be quickly or easily replicated, the firm can continue to use this advantage to outperform competitors, thereby maximizing the value created for the firm and its clients[5].

Unfortunately, knowledge-based assets are difficult to measure and manage. The same features that make many knowledge-based assets difficult to copy—their intangibility and long development times – also make them difficult to manage and apply on development projects. Team managers often fail to take advantage of these critical skills and information within the firm boundaries, bemoaning that product development would have been easier "if we only knew what we know". Good tools are therefore needed to assist managers in assessing the health of their intellectual capital base, to provide guidance on how to best allocate these resources, and to shape strategic decisions about the assets needed for future product development projects.

### *1.2. The Importance of Intellectual Capital in the Aerospace Industry*

Although knowledge plays a central role in all businesses, the U.S. aerospace industry has cause for concern about its intellectual capital. Aerospace managers are all too aware of the impact that staff downsizing and budget cutbacks has made on the underlying stock of corporate intellectual capital, with many skeptics questioning whether the aerospace industry is "losing the

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[5] This resource-based view of firm competitiveness, which emphasizes internal resources over external market forces, is discussed in Teece, "Dynamic Capabilities and Strategic Management", *Strategic Management Journal*, Vol.18:7, 1997.

recipe" to design and build new aircraft and military systems. These concerns, as well as data supporting these trends, have been highlighted in a number of recent publications:

- In an oft cited RAND study from the early 1990s, the declining number of military programs is leading to a declining experience level for aerospace employees, as designers are exposed to only one or two major programs over the course of their career. Given this trend, the study questions whether the nation's military aircraft design capability can be maintained, and suggests that the loss of staff and corporate capabilities poses a serious threat to U.S. defense capability[6].

- In articles written for *Aviation Week*, Scott[7] has highlighted the dramatic loss of human capital in the aerospace industry and its implications for future capabilities in the defense sector. Interviewees point to management failures, the lack of incentives, and the impact of downsizing on the loss of the aerospace workforce to other industries. Scott deems this as a "crisis" in the industry, predicting that the industry will be unable to maintain sufficient design skills and competitive production capabilities for future aircraft. This claim is also supported by the California Engineering Foundation[8] in its study of the industry.

- A report by the Global Aerospace and Defense Practices Group of Booz-Allen offers a gloomy assessment of the financial health of the industry, with significant drops in profitability and return-on-assets. The report identifies ten causes for financial woes and changes in workforce retention, including declining investments, limited access to capital, tight export restrictions, and the loss of workers to dot-coms and other industries. The report also notes that over 37% of undergraduate technical graduates from U.S. colleges are not U.S. citizens and thus ineligible for defense aerospace jobs, and that today's aerospace workers are more likely to change jobs and switch careers than ever before.[9]

- A recent M.I.T. white paper outlines the challenges of maintaining the aerospace workforce in the next century[10]. The paper points to the end of the cold war, the rise of global competition, and the employment drain to other high-tech business sectors as contributors to the loss of human capital in the industry. In particular, the study emphasizes the effect of funding instability and programmatic uncertainty on the industry's ability to maintain the staff and infrastructure for future programs. The paper cites that the average age of production workers in the US military sector is 53 years, with more than 20 percent eligible

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[6] Drenzer et al., "Maintaining Future Military Aircraft Design Capability", RAND, R-4199-AF, 1992.

[7] Scott, William B. "People Issues are Cracks in Aero Industry Foundation", *Aviation Week*, June 21, 1999, "Industry's Loss of Expertise Spurs Counterattack", Mar.13, 2000, "Worries Deepen Over Dearth of Technical Talent", April 23, 2001.

[8] *Mission Aerospace Executive Summary Progress Report*, California Engineering Foundation, Rancho Cordova, Feb. 2000.

[9] *U.S. Defense Industry Under Siege--An Agenda for Change*, John R. Harbison, General Thomas S. Moorman, Jr., Michael W. Jones, Jikun Kim, Booz-Allen & Hamilton, Los Angeles, CA, 2000.)

[10] Cutcher-Gershenfeld, Rebentisch, et al., *Developing a 21st Century Aerospace Workforce: Policy White Paper for the U.S. Commission on the Future of the Aerospace Industry*, 2001, http://web.mit.edu/ctpid/lara/policy

to retire in the next five years. With fewer young engineers entering into the aerospace workforce, the demographics indicate that a large staffing gap may result from the aging of the workforce.

While aerospace's attractiveness in a post-9/11 may be debatable, the demographics have not changed. Given this combination of demographics, increased global competition, the apparent inability to attract capital, and industry downsizing, the aerospace industry has been forced to pay increased attention to staff retention, knowledge capture, and knowledge management in the firm. Aerospace managers not only need to retain their intellectual assets for current programs, but must assess their stocks and forecast their requirements for intellectual capital in order to make strategic investment decisions for future programs. Intellectual capital needs to be managed not only for today's operations, but for tomorrow's opportunities.

### *1.3. Research overview*

The goal of this research is to shed some light on the role of intellectual capital within the firm – where it is, how it is currently used, and where it can be best applied to create value. In particular, the research seeks to identify tools and methods for measuring intellectual capital's contribution to organizational productivity in the U.S. aerospace industry. Seven product development projects at different aerospace firms were studied, using a case study methodology to investigate the underlying intellectual capital and its utilization in each project.

Based on these studies, this research uses the concept of intellectual capital as a "lens" for evaluating product development projects – as a means to identify critical knowledge-based resources that are utilized by product development teams. To help discern how these resources contribute to the product development process, projects of varying maturity were chosen to explore how the role of intellectual capital changes during different phases of product development. Whereas some of the cases have reached project completion and hardware delivery, other projects are still in the early conceptual phase of business case development – the so-called "fuzzy" front-end of the product development process[11]. Trends and differences between these cases help reveal how knowledge-based resources – including staff, processes, corporate structures, and external relationships – can lead to differentiated performance and project success.

Using this awareness of the role of intellectual assets in product development, a self- assessment tool is presented that allows organizations to measure and assess the health of their intellectual capital base. The self-assessment tool can empower managers by providing an improved understanding of intellectual capital in their firm, its usage, and its implications for project management. With this tool, senior-level managers can better structure the workforce, allocate resources, and optimize current operations for improved productivity. In addition, the tool and supporting research provide insights on the "fit" of intellectual assets with long-term product

[11] For more on the requirements of front-end PD processes, see Wirthlin, "Best Practices In User Needs/Requirements Generation", 2000, http://lean.mit.edu

development goals, serving as a guideline for resource acquisition and strategic planning for future product development projects. The results of this research can hopefully help managers leverage their firm's underlying intellectual capital for both operations and opportunities, and highlight areas where new capabilities need to be developed.

As an aid to understand intellectual capital and its use, this thesis begins by presenting an overview of existing research in the field. Chapter 2 looks at prior literature on the topic of intellectual capital, including the different definitions and taxonomies of intellectual capital in business journals and academic research. The literature review includes a discussion of the growing body of research on the financial measurement of intellectual capital – for example, the valuation of intellectual property and corporate intangible assets. It is important to note, however, that the emphasis of much of the prior literature is financial valuation. Although financial measures are important, they provide few insights to managers about how to assess the health of the organization, improve operations, or allocate resources. Rather than emphasizing the quantification or valuation of intellectual assets, the focus of this thesis is the use of intellectual capital as a tool for management and planning purposes.

In Chapter 3, a new conceptual framework is presented for understanding how three different types of intellectual capital – Human Capital, Structural (Organizational) Capital, and Relational Capital – are exchanged and transformed in an organization. Building on prior framings, a dynamic model is developed that portrays specialized knowledge and organizational learning as the "stocks" and "flows" of intellectual capital. The material in this chapter serves as the foundation of the research effort – its goal is to provide a conceptual understanding of intellectual capital that supports the rest of the thesis work. The presented framework defines what intellectual capital is, and develops a coherent mental model of intangible assets that are constantly changing and often hard to define. The framework identifies mechanisms for the creation and evolution of intellectual capital and, importantly, how it can be used to create value for a firm and its clients.

In addition, the chapter explores the importance of human capital, its central role in intellectual capital development, and the dynamic nature of staff knowledge in today's aerospace projects. The chapter emphasizes that different timescales are needed for the development of staff knowledge, organizational tools and processes, and external relationships with customers and suppliers. These temporal differences – and especially the timescales for the creation and the perishability of these different types of intellectual capital – have important implications for corporate managers who seek an appreciation of their firm's critical skills and knowledge-based assets.

Next, the framework is bolstered by data from the case studies of seven product development projects at different aerospace firms. The case studies, which represent the bulk of the thesis work, are based on data collected from site visits to each of the project teams. When selecting case studies for this research, projects were chosen to provide both commercial-oriented and military aerospace development efforts, with some projects having dual-use applications. The cases also represent projects in different stages of maturity during the product development cycle.

Each project involved the development of a complex product – hardware or software – that required the tacit and explicit exchange of knowledge between design team members, managers, clients, and critical suppliers. These case studies include interviews, anecdotal stories, and "lessons learned" from each product development effort, highlighting the knowledge-based resources that were used (or needed) during each project. As a whole, these projects exemplify how firms can apply their intellectual assets to develop new products, and provide crucial insights about knowledge transfer and the role of intangibles in product development. The instructional value that can be gained from real-world case studies is essential to a meaningful study of intellectual capital, and therefore forms the backbone of this research.

Following the case studies, a comparative analysis is presented that calls attention to key findings from the effort. Here, similarities and differences between the case studies are reviewed, with common traits identified as either enablers or disablers in the product development process. The diversified mix of projects chosen for the case studies allows for pattern matching and explanation building from the research data, and provides important clues about the types of intellectual capital that are needed for successful projects. By investigating the causal relationships between intellectual capital and the success or failure of product development projects, the case studies provide the grounding needed to test hypotheses from the framework about the role of intellectual assets in aerospace firms.

The analysis section culminates with a self-assessment tool that managers can use to assess the health of their intellectual capital base. To highlight common themes from the case studies, intellectual assets are grouped to form a "capability matrix" that identifies specific resources and activities that enable value creation. From these matrices, managers can see which activities tend to promote the development of relational capital, the creation of structural capital, or the enhancement of human capital in firms. No tool can provide a "silver bullet" for completely understanding the myriad of factors that lead to project success or failure. It is hoped, however, that the findings presented here will promote an awareness of intellectual capital and its role in aerospace product development, leading to improved operational efficiency and better strategic planning for future projects.

Although the U.S. aerospace industry may be facing an unprecedented crisis with maintaining its intellectual capital, it is not the only industry that faces this dilemma. The results from this study are generalizable to other industries with products involving a high degree of technological complexity, or providing highly complex services to their clients. The challenge that faces many project managers today is not only "knowing what we know", but being able to apply lean principles towards fully leveraging their intellectual assets and creating value across their enterprise. Understanding what intellectual capital is, and how it can be used, is one of the first steps towards achieving lean enterprise value.

## 2. Literature Review

### *2.1. Introduction to Intellectual Capital Research*

Although intellectual capital has recently acquired "buzzword" status, its central issue – of knowledge and its role in the firm – dates back to Adam Smith and the industrial revolution. Interest in intellectual capital has blossomed, however, with a revolutionary paradigm shift in the business world: the onset of the so-called "information economy".

Despite the burgeoning of literature in the last few years, research on intellectual capital and its relevance to the business community is still in its infancy. Most researchers to date have attempted to measure intellectual capital by making a correlation to existing financial measures, such as market-to-book ratios. Some of this research emphasizes financial valuation, without an understanding of underlying assets and their contribution to value. Considerable work needs to be done, however, to develop practical tools for managers – to allow them to identify, develop, and exploit the intellectual capital in their firms.

To embark on this effort, I try to cover three areas in this chapter:

— An introduction to intellectual capital, including a definition of terms
— A review of existing literature in the field
— A discussion of questions that are unanswered by the literature, and what's needed to further advance the research topic

Before exploring its role in product development, it's helpful to have an understanding of what intellectual capital is, as well as where it resides in the firm. I discuss how researchers have developed different taxonomies for categorizing intellectual capital, to provide an appreciation of how the topic has evolved in the published literature. To help frame this prior research, I also review some of the analytical frameworks that address the role of knowledge in firm competitiveness and organizational theory. This supporting material provides a foundation for understanding intellectual capital's role in providing competitive advantages and creating value for a firm and its clients.

Finally, I have included a critical discussion of gaps and unanswered questions raised by the literature. With this literature review, I hope to establish the need for a new framework for explaining intellectual capital – one that captures the dynamic nature of intellectual capital assets and how they are used to create value.

### *2.2. Defining Intellectual Capital*

What exactly is intellectual capital? Like many abstract concepts, there are as many definitions as there are researchers in the field. However, Thomas Stewart, a columnist for *Fortune* Magazine, succinctly defines intellectual capital as "intellectual material -- knowledge, information, intellectual property, experience -- that can be put to use to create wealth".[12]

[12] Stewart, Thomas A., *Intellectual Capital*, Currency Doubleday, 1997.

Immediately, two important distinctions can be drawn from this definition. The first is that intellectual capital refers to "material", or better yet, "assets" that are knowledge-based. The critical feature that distinguishes intellectual capital from other corporate assets is the underlying knowledge or "know-how" that can provide a firm with unique competitive capabilities. Note that this definition does not imply that all intellectual capital must be intangible – for example, intellectual property such as patents and copyrights are tangible corporate assets that can be financially valued, licensed, and sold. Nor does it imply that all physical objects are devoid of intellectual capital – most manufacturers can attest to the all-important, task-specific knowledge that is embodied by their facilities and production lines. Rather, the definition of "intellectual capital" emphasizes that knowledge is the critical attribute that is embedded in the services and products of today's businesses.

The second distinction is the vital link to wealth and value creation – a linkage that is implicit in terminology such as "capital" and "assets". Intellectual material, whether in the form of staff knowledge, corporate databases, or even patents, does not create value if it is never applied towards meeting current challenges or developing new products and services. For instance, archived documents and design data have no value unless they can be accessed for new projects, allowing staff to search, retrieve, and apply relevant knowledge from past programs. Instead, true intellectual capital is characterized by its accessibility, relevance, and usefulness in creating value – either by advancing corporate goals, satisfying client needs, or both. (Note that these applied, practical characteristics are also at the heart of the distinction between "information" and "knowledge"). In summary, knowledge derives its worth through its application, and intellectual capital describes those knowledge-based assets that can potentially create value for a firm and its clients.

Knowledge and its role in creating value are hot topics in today's business environment, and for good reasons. Like other analysts, Thomas Stewart has championed that a fundamental paradigm change has occurred in the business world, with a shift towards an information-based economy. These changes have also been heralded by business visionary Peter Drucker, who emphasizes the importance of the "knowledge worker" in a knowledge-based society and its implications on the governance of firms.[13] Not only are knowledge-based assets more important today, but it can be argued that they are also harder to identify and manage in an information-rich age. With advances in today's IT systems, it is easier to become lost in the pursuit of "information for information's sake", without effectively managing key knowledge assets that can generate competitive advantages and associated profits. We have become inundated with information at the same time when knowledge-based assets have taken on increased importance, thus compromising our ability to manage critical corporate knowledge.

[13] Drucker, Peter F. *Management Challenges for the 21st Century.* Harper Collins, 1999.

### *2.3. Categories of Intellectual Capital*

For these reasons, managers and researchers alike have been devoting increased attention to the topic of intellectual capital. To grapple with the diversity of knowledge-based assets, many researchers distinguish between three types of intellectual capital:

- Human capital,
- Structural capital, sometimes referred to as "organizational" capital, and
- Relational capital

#### *2.3.1. Human Capital*

Human capital consists of the individual knowledge and skills embodied in a corporation's employees – the primary source of intellectual capital for any firm. At a fundamental level, the workforce's knowledge and capabilities serve as an engine, allowing corporations to operate, innovate, execute, and adapt to changing business conditions. In this sense, human capital is the most dynamic form of intellectual capital, as it allows a firm to flexibly and rapidly respond to new challenges. It is also the most dynamic and difficult to manage, since it depends upon staff retention as well as the effective use of individual abilities.

Beyond the explicit, task-oriented skills of the workforce, human capital consists of knowledge and capabilities that are inherently tacit in nature and, accordingly, can be extremely difficult to define and manage. Examples of human capital in the workplace include:

- *The "talent pool" constituted by a company's staff members*, including their ability to design, innovate, and create new products and services. Measures such as industry experience (i.e. number of years, number of design cycles) and the knowledge base of the workforce (e.g. certifications, degrees held) are sometimes used as indicators to assess the health of a company's human capital.
- *The capability of staff members to perform collaborative work.* Beyond individual knowledge and skills, human capital also consists of the ability of staff to communicate, express ideas both verbally and in written form, and to effectively translate knowledge across personal boundaries.
- *Personality traits that enable collaborative work*, including the individual's personal norms and values, openness to learning and personal growth, and willingness to trust others. These traits are essential for "working well with others" in a collaborative, team environment.
- *Corporate awareness about "how things work around here".* A knowledge of corporate norms and processes can enable staff members to be effective agents within their company, and therefore is a form of human capital that can promote project success.
- *An industry-wide knowledge of resources and suppliers.* Likewise, human capital includes an individual's knowledge beyond the walls of the firm, including a strategic awareness of potential partners and an understanding of the industry's competitive landscape.
- *Corporate managerial and leadership skills*, since an experienced management team is the ultimate piece in the firm's human capital base. Senior management must not only have the requisite management skills, but needs to be able to lead by example, motivate, and articulate both operational and strategic goals to their teams. Clearly, each individual staff member

contributes by bringing their own unique combination of human capital assets to the workplace.

Many researchers and practitioners consider human capital as the preeminent component of a firm's intellectual capital base. Yet despite this, there is very little data that unambiguously correlates investments in human capital – staff education and training, for example – to return-on-investment (ROI) and financial success. The complexity of measuring the ROI for human capital investments, combined with the lack of incentives for public data disclosure, has led to the almost universal supposition of human capital's importance without well-documented, corroborating research. As for practitioners, many managers are intent on assessing these various forms of human capital, as well as understanding their impact on project success, but the task is daunting. Given the lack of universally accepted metrics for the quality of a firm's human capital base, the result is that what isn't measured is often not well-managed, either.

### *2.3.2. Structural Capital*

Human capital alone is not sufficient for product development; it needs an organization in order to exploit its value. To complement a firm's human capital, structural capital (or "organizational" capital) provides the necessary infrastructure for coordinating efforts and turning knowledge into products. As with other types of intellectual capital, it emphasizes the importance of knowledge-based assets in the production function. Unlike human capital, however, structural capital represents a company's "know-how" that is embodied in corporate processes, tools, and organizational structure. It includes a firm's unique capabilities, proprietary tools and data, corporate technologies, intellectual property, as well as structures and mechanisms that aid in collaborative design and project execution. To extend an earlier metaphor: if human capital is an "engine" for the firm, then structural capital serves as its "vehicle" for product development and value creation.

An important distinction here is that structural capital resides within the firm's domain, and is the easiest form of intellectual capital for managers to employ. Leif Edvinsson, who played a pioneering role in managing intellectual capital at Skandia, points out that "structural capital doesn't go home at 5pm, or quit and hire on with a rival".[14] Structural capital is therefore the form of intellectual capital that is most clearly owned and controlled, despite the intangible nature of most knowledge-based assets. Note that structural capital extends well beyond the physical tools of manufacturing, i.e. production lines and capital equipment. Rather, structural capital is corporate knowledge – embedded in both the tangible and intangible infrastructure of the firm – that results in unique capabilities, allowing workers to collaboratively deliver new products and services. This concept is at the core of what managers refer to as their "organizational know-how" or "corporate intelligence".

Structural capital takes on many forms, including:

[14] Leif Edvinsson, "Developing Intellectual Capital at Skandia", *Long Range Planning* v.30 no.3, pp.366-373, 1997. See also Stewart, "Your Company's Most Valuable Asset: Intellectual Capital", *Fortune*, pp.68-74, 10/3/1994.

- *The intellectual property of the firm.* A company's patents and copyrights are one of the most tangible forms of its structural capital. Trade secrets are also part of a firm's structural capital, which are often tangibly valued when business units are sold or merged.
- *Business practices, including processes and procedures,* are perhaps the most ubiquitous form of structural capital in large firms. Business processes, whether formalized or informal, represent the valuable corporate knowledge gained from past projects, codified into the operating procedures of the firm. This proprietary knowledge is critical for industries that provide complex products and services; in fact, some recent efforts to formally patent these business practices serve as a testament to their value[15]. In particular, lean business practices add to a firm's structural capital, as they emphasize this infusion of this knowledge into all aspects of the workplace.
- *Intelligent tools for design and manufacturing* are components of structural capital, especially when firms customize equipment and couple systems to create novel, unique capabilities. For example, knowledge gained from previous projects is often embedded in the tools that aid in production processes, especially those with highly repetitive tasks. This corporate-specific knowledge is embedded in both business practices and the machinery or "tools" of production, with companies benefiting from synergies when these resources are combined.
- *Corporate knowledge in the form of documents, manuals, and databases* that has been captured from previous projects. Complementing the tacit experience base of the workforce, this data represents the explicit portion of "corporate memory" which can be re-used for new projects. This knowledge remains with the firm, regardless of staff retention and the effects of "corporate amnesia". However, as mentioned earlier, this captured knowledge must be both accessible and relevant for it to be useful in creating value.
- *IT and networking systems* for knowledge-capture and knowledge-sharing within the firm. Information systems are an essential component of structural capital in today's workplace, as they serve to capture, organize, and disseminate knowledge throughout the firm. With large project teams, these IT tools are a necessity for the coordination of efforts, transfer of knowledge, cross-pollination of ideas, and interdisciplinary collaboration during product development.
- *Organizational structure and management resources* are also an aspect of a firm's structural capital, providing an administrative foundation that is necessary for any collaborative project. The structural capital of a firm includes its organizational resources – for example, its reporting structure, support functions such as R&D, divisional structure, matrix organization for projects, etc. – that define roles and provides authority for managing tasks. This hierarchy is fundamental to the command, control, communications, and intelligence ($C^3I$) of the company, so the organizational structure must be appropriate for the projects and tasks that are undertaken.

[15] Two prominent rulings on the patenting of business methods are *State Street Bank & Trust v. Signature Fin. Group*, 149 F.3d 1368 (Fed. Cir. 1998), and *AT&T Corporation v. Excel Communications, Inc.*, 50 U.S.P.Q. 2d 1447 (Fed. Cir. 1999).

- *Organizational culture*, although difficult to categorize, can at times be considered a part of a firm's structural capital. It can be argued that a corporate culture that fosters knowledge exchange and learning, or encourages experimentation and risk taking, is an intangible asset that adds value and is owned by the firm. An organization's culture, however, is intimately tied to the attributes of its human capital, and therefore seems to straddle the line between these two categories of intellectual capital.

Despite this broad diversity of structural assets, many managers focus solely on their IT systems as the primary tool for capturing and managing corporate knowledge. Computer-based expert systems are developed that try to capture the expertise of a workforce that cannot be supported or retained in today's competitive environment. Large investments are made in computers and networks to facilitate the transfer of knowledge through the firm. As can be seen above, structural capital is much more than IT systems for capturing knowledge. Knowledge management efforts need to consider all knowledge-based assets that reside within the firm's control, including the varied range of structural capital that can be applied towards value creation.

### *2.3.3. Relational Capital*

In addition to human and structural capital, companies benefit from their relationships with suppliers, partners, and clients. No company is an island; to succeed, it must constantly exchange knowledge with the client community that it serves, developing an awareness of both potential clients and their needs. It must also nurture relationships, both formal and informal, with the supply chain that provides the essential components for its products. Relational capital, the third category of intellectual capital, emphasizes the value that a firm derives from these relationships with external actors – individuals and companies that are outside of the boundary of the firm.

This is an important distinction from the relationships between employees of the firm. Relational capital – sometimes referred to as "customer capital" – derives its value from the knowledge exchange with outside parties. Relational capital, however, is more than a firm's customer base; it includes all of the mutually-beneficial collaborations outside of the firm. Suppliers, partners, regulatory agencies, shareholders, capital markets, and indirect clients are all part of the stakeholder community that contributes to a firm's relational capital. As a form of intellectual capital, it emphasizes the value of the corporate knowledge gained from these exchanges, and the strategic benefit derived from intangible relationships with these external actors. Clearly, some firms are better positioned in their market due to the quality of their relational capital, and their ability to utilize these assets to their competitive advantage.

In some sense, relational capital is similar to the shared partnership between a firm and its human capital. Although it can be managed, relational capital resides outside the strict control of the firm. It can be both formalized – such as contracts and strategic partnerships – and informal in its nature. Example of relational capital include:

- *The relationship between a firm and its long-term clients.* A company's clients represent the key source of a firm's relational capital. Customers help identify growth areas and market opportunities, provide feedback on the quality of services, and contribute to the firm's reputation in the industry. An intimate knowledge of a client's needs, and what they're willing to pay for them, are the most essential aspect of a firm's relational capital.
- *Interactions with potential clients.* In a nutshell, marketing's role is to build relational capital. Firms must be able to identify potential clients, understand their needs, and develop the relationships needed to win new contracts.
- *Brand equity and customer loyalty* are the result of these strong firm-to-client relationships. Built upon past performance, an awareness of client needs, and the ability to respond to those needs, it is one of the more tangible forms of relational capital.
- *Knowledge of the competitive landscape.* Firms also must be aware of its competition, as well as the competitive price that the market will bear for its goods and services. Often, a company's relationships with its competition can be as important for intelligence gathering as relationships with its clients.
- *The value of a firm's supply chain* cannot be underestimated in today's globally-connected marketplace. Strong supplier relationships are essential for exchanging critical knowledge about capabilities, manufacturing tolerances, interfaces, delivery schedules, and the myriad of details necessary for delivering integrated products and services. Whereas linked databases and management software represent an investment in shared structural capital, it is relational capital that provides the foundation for supply chain development, coordination, and integration.
- *Partnerships and strategic alliances* represent another form of relational capital that has been explicitly formalized thru contracts between firms. These alliances are mutually beneficial arrangements that provide a source of lasting value for both firms, and are therefore one of the most enduring forms of relational capital.
- *Relationships with government and regulatory agencies* are indispensable requirements for the aerospace industry, as well as any firm that provides complex products in a global marketplace. To be successful, firms need to identify potential stakeholders, consider the political aspects of the funding process, and understand the regulatory hurdles that must be overcome to deliver products or services.
- *Relationships with shareholders and the financial markets.* Finally, relational capital includes a firm's relationships with its board of directors, stockholders, key financial stakeholders, and the financial markets in general. Significantly, these relationships directly impact the market valuation of the firm, and help determine the cost of capital that a firm must bear.

Most of these types of relational capital are intangible – not surprising, given the nature of relationships as a whole. The consequence, however, is that relational capital is the most difficult category of intellectual capital to acquire, manage, and successfully sustain. Mutually beneficial relationships can take years to develop, and are built on a history of past performance and trust. Thus, relational capital takes the longest time to develop and, despite efforts to manage it, is often subject to factors that are beyond management's control. Still, relational capital is an essential complement to human and structural capital, forging unique alliances of resources and difficult-to-imitate capabilities for firms.

## *2.4. The Evolution of Intellectual Capital Research*

### *2.4.1. Early contributions to intellectual capital research*

Although the term "intellectual capital" was first used by Thomas Stewart in a 1991 *Fortune* magazine article on brainpower as a corporate asset[16], the topic clearly evolved from interest in the role of corporate knowledge in successful businesses. Some of intellectual capital's roots can be traced overseas – first, to Japanese companies whose business culture emphasized the role of knowledge in the firm. This trend was first captured by Itami in his seminal work on the importance of developing and utilizing intangible, "invisible" assets.[17] In his book, Itami identifies knowledge and information as the "real source of competitive power" that "are hard to accumulate, capable of simultaneous multiple uses, and are both inputs and outputs of business activities." Itami's work also pioneered the development of a holistic view of intellectual capital – one that emphasizes the alignment or "fit" of these assets within the relational and organizational context of the firm. Itami's emphasis on intangible, knowledge-based assets serves as the formative basis for much of the succeeding work in the knowledge management field.

Intellectual capital's roots also lie in the work of researchers at Swedish businesses such as Skandia in the early 1990's. As interest spread in the burgeoning field of "knowledge management", Swedish researchers began to examine the different roles that human-based and firm-based knowledge played in their firms. As a leader in this movement, Leif Edvinsson describes the development of an Intellectual Capital function at Skandia[18], starting with the establishment of a Director of Intellectual Capital in 1991. Based on the knowledge management articles by Swedish researcher Sveiby[19], Edvinsson and managers at Skandia began to develop a methodology for identifying and categorizing knowledge-based assets, and attempted to create reporting data which tracked these assets at the firm. This effort eventually led to the first inclusion of intangible assets in a corporate annual report, which Skandia published as a supplement to their 1994 annual report[20].

### *2.4.2. The development of intellectual capital taxonomies*

Like many of the researchers that followed in their steps, Skandia's managers used an accounting approach to categorize intellectual capital. Their 1994 supplement begins by drawing parallels between knowledge-based assets and the firm's conventional assets, noting that intellectual capital must be accountable for the difference between a firm's book value and its market value.

[16] Stewart, Thomas A. "Brainpower", *Fortune* Magazine, June 3, 1991, pp.44-57.
[17] Itami, H., *Mobilizing Invisible Assets*, Harvard U. Press, 1987. Published earlier in Japanese.
[18] Edvinsson, Leif. "Developing Intellectual Capital at Skandia", *Long Range Planning*, Vol.30 No. 3, 1997, pp.366-373.
[19] See, for example, Sveiby, Karl Erik, *The New Organizational Wealth*, San Francisco: Berrett Koehler, 1997.
[20] "Visualizing Intellectual Capital at Skandia", *Supplement to Skandia's 1994 Annual Report*, http://www.skandia.com/en/ir/annualreports.shtml

This assertion – that a firm's intellectual capital is measured via the market's valuation of its stock – has formed the cornerstone for much of the intellectual capital research to date. Later in this chapter, I will explore some of the underlying assumptions and analytical frameworks that support this assertion.

Figure 2-1 shows Skandia's taxonomy of intellectual capital from the 1994 supplement, showing the division of value between intellectual capital and "shareholder equity" or book value. Skandia's managers initially categorized their firm's intellectual capital as divided only between its human capital and structural capital, with "customer" capital as a subset of the firm's structural capital. Edvinsson further decomposes organizational capital into innovation capital and process capital. This distinction suggests that structural capital can serve two purposes: adaptation for new opportunities, or capture of repetitive processes. According to the Edvinsson, the goal of Skandia's management is to transform human capital into structural capital, capturing the transient nature of human knowledge assets and embedding them in the organization. The function of the firm's Director of Intellectual Capital, then, is to facilitate this knowledge capture and help develop the tactics and strategy for value creation from these assets.

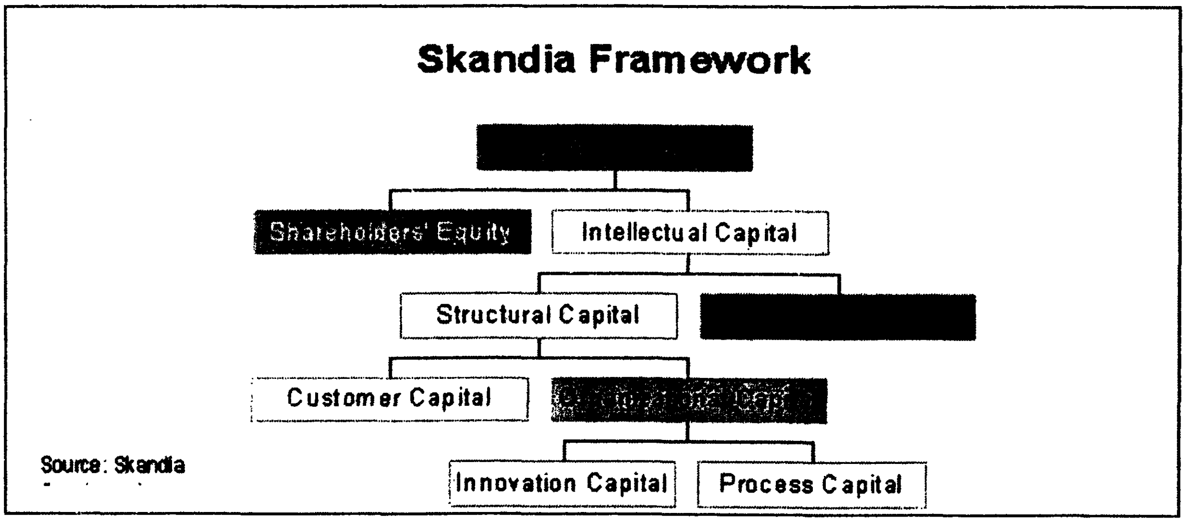


**Figure 2-1 – Skandia framework (from 1994 annual report)**

Skandia's inclusion of "customer" capital in their taxonomy draws upon the work of Canadian researcher Hubert Saint-Onge, who saw the importance of a firm's relationship with its clients[21]. To St. Onge, a firm's human and structural capital only created value when it provided solutions for its clients. Strong relationships within a wide, deep, and loyal client base therefore represent intangible assets to the firm. By making customer capital a subset of a firm's structural capital, however, Edvinsson and Skandia's managers assert that these client relationships are assets that are owned by the firm, and are clearly separate from the firm's captured organizational capital. Although it emphasizes the importance of the client base, this framing does not account for the

[21] See Saint-Onge, Hubert, "Tacit knowledge: The key to the strategic alignment of intellectual capital", *Strategy & Leadership* v.24 no.2, Chicago, Mar/Apr 1996, and references from Stewart, Intellectual Capital, 1997.

value that suppliers, partners, and other external actors bring to the firm, nor does it acknowledge that these relationships are not solely within the firm's control.

After Skandia's 1994 report, Scandinavian firms continued to explore the concept of intellectual capital, experimenting with ways to categorize assets and developing different reporting methods. Building upon Skandia's efforts, Roos and Roos developed a roadmap of intellectual capital based on their study of five Scandinavian firms[22]. Relying on interviews of corporate managers, Roos and Roos decomposed intellectual capital into the taxonomy shown in Figure 2-2. In the figure, "customer and relationship capital" has been elevated to a distinct, primary category from structural capital, and the list of external actors is expanded to include suppliers, partners, and financial stakeholders such as investors. Structural capital, termed as "organizational capital" in the figure, is divided between processes and business renewal & development capital. Roos and Roos note that these categories are supported by their interview data, although the article does not elucidate on the distinctions between subcategories. However, their taxonomy provided one of the first systematic tools for visualizing a firm's knowledge-based assets, providing a starting point for managers to think about the role of intellectual capital their firms.

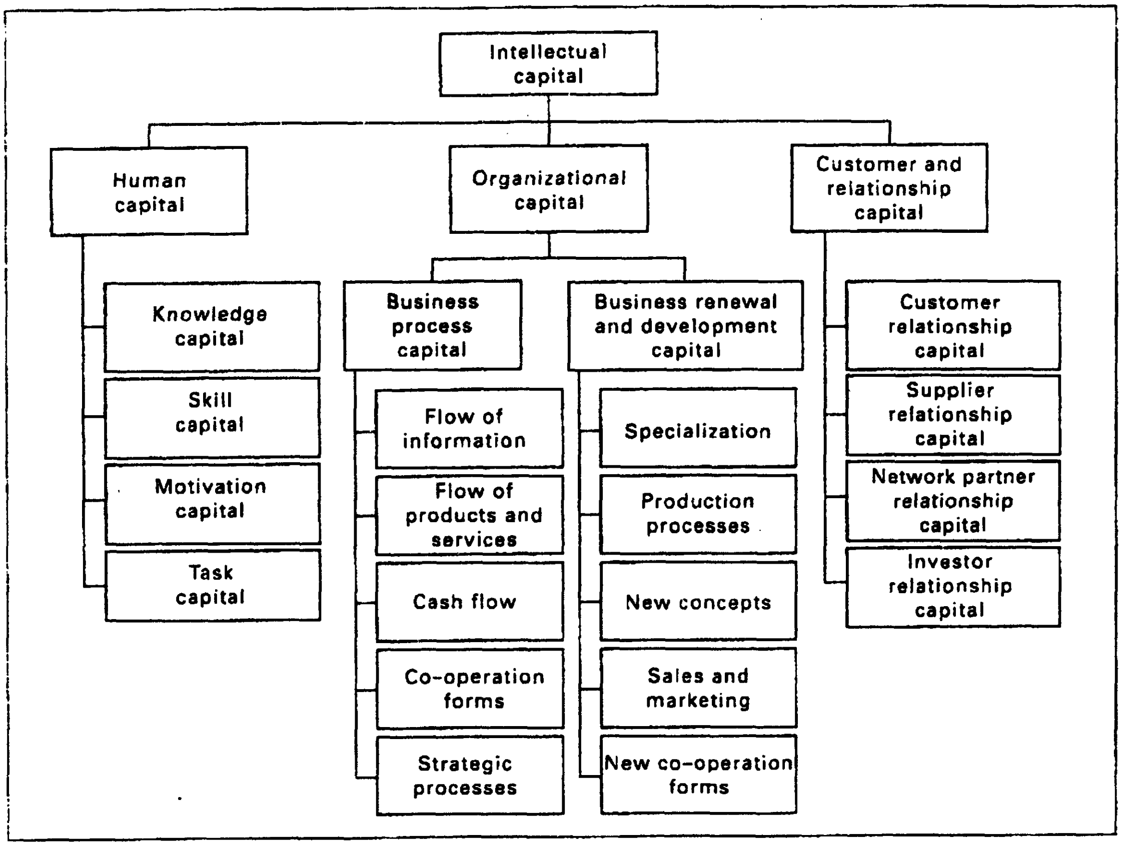


**Figure 2-2 – Taxonomy of intellectual capital (from Roos & Roos)**

[22] Roos, Goran and Roos, Johan. "Measuring your Company's Intellectual Performance", *Long Range Planning,* Vol.30 No. 3, 1997, pp.413-426.

Using this taxonomy as the basis for further research, Roos and Roos returned to the firms in an attempt to identify outcome measures and causal relationships between assets and performance. As part of this effort, they developed samples of intellectual capital "balance sheets", which attempted to illustrate changes in intellectual capital over different reporting periods. Unfortunately, their balance sheet approach fails to explain the flow mechanisms between these intellectual capital stocks, nor the intervening variables that control these flows. However, Roos & Roos recognized a number of important points: first, that intellectual capital is a dynamic process, with constantly changing stocks of knowledge-based assets that are transformed between categories. To capture its dynamic nature, they utilized financial analogies – such as balance sheets and profit & loss statements – to evaluate intellectual assets and their changes. Finally, Roos and Roos' work emphasized the relationship between intellectual capital and strategic planning. They stressed that the intellectual capital identification process is meaningful only when it is linked to planning; namely, that the weighting of different intellectual assets is firm-specific and inextricably embedded in the firm's strategic goals. In other words, each firm has to find the "right mix" of intellectual capital to successfully execute its strategic plan.

### *2.4.3. Refinements to intellectual capital models*

With escalating interest in intellectual capital – and more collaboration between practitioners, researchers, and industry analysts – the volume of published literature continued to grow. Many of these researchers began to develop new tools for measuring and managing intellectual capital, based on the realization that traditional accounting tools were no longer effective for corporate planning in a knowledge-based economy.

For example, Skandia's internal experience with intellectual capital had evolved into management tools for other firms. By 1997, managers at Skandia had refined their model, elevating the importance of customer capital in their taxonomy (see Figure 2-3). In support of this new model, Skandia began to offer intellectual capital business services as a product line, including software to help managers identify assets, develop scorecards, and define metrics to track changes in knowledge-based assets over time. Similar to Norton and Kaplan's balanced scorecard, Edvinsson advocated that managers should use the "Skandia Navigator" to focus on key areas of interest – customer, process, people, and business renewal and development – and develop non-financial metrics to gauge firm performance in these areas[23].

[23] Skandia's model is documented in Leif Edvinsson and Michael Malone, *Intellectual Capital: Realizing Your Company's True Value by Finding Its Hidden Brainpower,* HarperBusiness, March 1997.

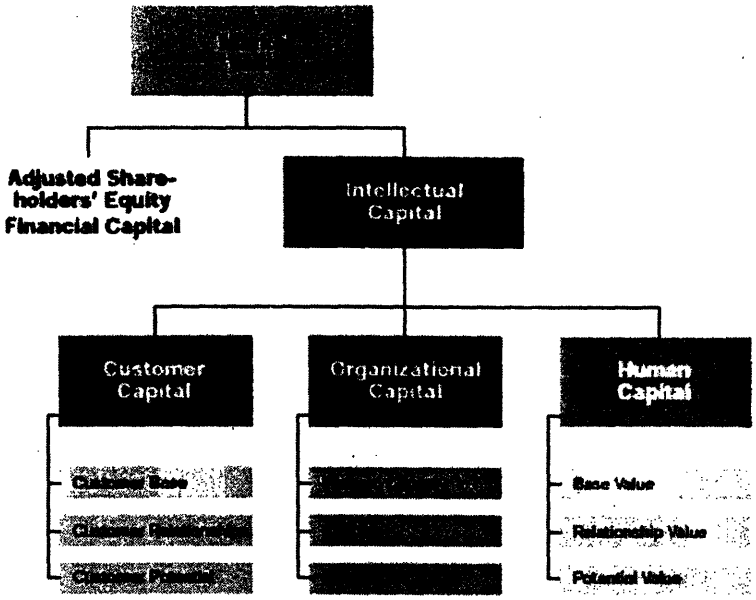


**Figure 2-3 -- Revised Skandia taxonomy (from 1998 annual report)**

At this same time, Thomas Stewart's newly published book, *Intellectual Capital*[24], became the most widely disseminated literature in the field. Stewart's 1991 and 1994 *Fortune* articles[25, 26] on intellectual capital had been enthusiastically received, and his follow-up book quickly made a number of best-seller lists. Drawing upon Edvinsson and Roos & Roos, Stewart explains the three-tiered categorization of intellectual capital in Swedish firms, but supplements this with anecdotal examples of intellectual capital implementation (as well as mismanagement) in various firms. Given his style, his target audience is clearly the broad business community, not researchers. In between these stories, Stewart develops some intellectual capital management guidelines for managers and practitioners. For example, Stewart suggests that managers focus on group phenomena, such as social learning and team structures, to encourage human capital development while still promoting knowledge capture for the firm. Sensing the underlying tension between staff retention and efforts to codify tacit knowledge, Stewart sees social, collaborative efforts as simultaneously developing both human capital and corporate knowledge – a win-win arrangement for both individuals and firms. Based on his interviews, Stewart also offers a set of key outcome measures for intellectual capital development, including:

- Percent of sales from new products
- Employee satisfaction
- Experience, turnover rates, and rookie ratios
- Market-based evaluation of technology and structural capital assets
- Customer satisfaction and retention
- Overall financial measures, including market-to-book ratios and Tobin's Q

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[24]Stewart, Thomas A., *Intellectual Capital,* New York: Currency Doubleday, 1997.
[25]Stewart, Thomas A., "Brainpower", *Fortune Magazine*, June 3, 1991, pp.44-57.
[26]Stewart, Thomas A., "Your Company's Most Valuable Asset: Intellectual Capital", *Fortune,* October 3, 1994, pp.68-74.

Although his emphasis is on practical business advice, Stewart's book makes significant contributions for researchers in the intellectual capital field. Stewart's work serves to coalesce a wide range of prior literature on of intellectual capital, knowledge management, and the role of knowledge in the workplace. He devotes a considerable portion of his book towards the importance of intellectual capital in the context of the new "information age". Taking a confident stance on the issue, Stewart describes the information economy as a revolutionary paradigm shift, where knowledge assets continue to replace physical assets as the critical components of production and value creation.

Of course, Stewart is not alone in this conclusion. Business visionary Peter Drucker[27] has written on the importance of the "knowledge worker" in a knowledge-based society and its implications on the governance of firms in the 21st century. Sveiby[28] also touted the emergence of "knowledge organizations" and the reduction of competitive advantage to purely knowledge-based assets, claiming that management's foremost responsibility is to develop corporate knowledge. Finally, Neef[29] has edited a solid collection of essays on the changing economic landscape, the role of intangibles, and the implications for industry and government regulation. These authors suggest that, in today's business environment, knowledge has been established as the basic unit of economic activity – with a company's intellectual capital as its critical resource for value creation.

### *2.5. Other Supporting Research*

In a letter to Robert Hooke, Isaac Newton once commented that "if I see further, it is because I stand on the shoulders of giants." Similarly, the field of intellectual capital is greatly indebted to researchers who laid the foundation of modern organizational theory. Although Stewart, Edvinsson, Itami, and Roos and Roos helped establish a popular awareness of the concept of "intellectual capital", their work rests on the analytical frameworks of these researchers, especially those who explored how organizational knowledge is transformed and used to gain competitive advantage. It is worth highlighting some of the important works in organizational theory and knowledge management that support the concept of intellectual capital.

#### *2.5.1. Resource-Based View of Competitiveness*

The ultimate goal of exploiting intellectual assets is to develop a competitive advantage for the firm – ideally, one that can lead to sustainable profits. But does superior intellectual capital really lead to a competitive advantage? To answer this question, we should first consider how firms compete with one another. Much of the early management literature was conceptually grounded in a market-based perspective of the firm, where strategy was determined by factors external to the company. Given the presence of competitors in each business sector and the market demand for product, each firm optimized its production function in an effort to reach a

[27] For a good summary of his writings on this topic, see Drucker, Peter F., *Management Challenges for the 21st Century,* Harper Collins, 1999, and *The Essential Drucker*, HarperBusiness, 2001.
[28] Sveiby, Karl Erik, *The New Organizational Wealth*, San Francisco: Berrett Koehler, 1997.
[29] Neef, Dale, ed., *The Knowledge Economy*, Boston: Butterworth-Heinemann, 1998.

more favorable position on the supply-demand curve. Based on this view, it was external forces that determined firm strategy, allowing companies to establish market positions with competitive advantages.

Instead, other researchers (see Penrose[30], Teece[31], and recent summary by Bontis[32]) made an important distinction about competitiveness, developing a conceptual alternative that emphasizes a resource-based view of the firm. In this view, firms possess discrete assets that are difficult to imitate; it is these assets that are the source of competitive advantage in their business sector. This framing internalizes the factors that lead to firm success, and suggests that managers concentrate on the acquisition and development of critical strategic assets. In a historical context, these researchers suggested that manufacturing-intensive industries should focus on internal investment – e.g. capital equipment and other tangible assets – to create unique capabilities that lead to cost-efficient production. With the recent emergence of the knowledge-based economy, it is now intellectual capital that is framed by this resource-based view of the firm. Like tangible assets, a firm's knowledge-based assets and intellectual capital are resources that provide unique and difficult-to-imitate capabilities, which can lead to value creation and competitive advantage.

### *2.5.2. Role of Knowledge in Organizations*

In addition to theories of competitiveness, intellectual capital research draws upon basic conceptual frameworks about knowledge and its role in the firm. There is a wealth of literature that aims at defining what "knowledge" is, and how it is used in a corporate setting.

Rather than reviewing the copious material on corporate knowledge, it is important to acknowledge a few of the recent contributions to the field. The emergence of the information economy, combined with increased interest in knowledge management, has reinvigorated studies on the nature of knowledge and its role in an organizational context. For example, Bohn[33] provides a thoughtful summary of the how knowledge emerges in a high-tech context. During the development of complex products, knowledge of an underlying technological issue progresses from a stage of complete ignorance to process characterization and complete understanding. In the model of a competitive high-tech firm, many developmental technologies are in low stages of knowledge development, with new unknowns emerging as technical issues are advanced to higher stages. As firms "push the edge" to develop these enabling technologies, unknowns are not only necessary, but serve as an indirect indicator of the firm's willingness to acquire new knowledge. Contrary to expectations, the dominance of well-developed

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[30] Penrose, Edith, The Theory of the Growth of the Firm, New York: Wiley, originally published 1959.

[31] Teece, David J., "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy", *Research Policy* v.25, 1986. For his views on intellectual capital, see Teece, "Capturing Value from Knowledge Assets: The New Economy, Markets for Know-how, and Intangible Assets", *California Management Review,* vol. 40, no.3, 1998.

[32] Bontis, Nick. "Managing organizational knowledge by diagnosing intellectual capital", *Int. J. Technology Management,* Vol.18 No.5/6/7/8, 1999, pp.433-462.

[33] Bohn, Roger E. "Measuring and Managing Technological Knowledge", *Sloan Management Review*, Fall 1994, pp. 61-73.

technologies in an R&D portfolio can actually be an indicator of a lack of organizational learning. The role of the managers, then, is to effectively manage all levels of knowledge in a continuously evolving learning environment.

Grant[34] also develops this concept of the firm as a "knowledge processing entity" in his knowledge-based theory of the firm. Grant frames the firm in an organizational context, where knowledge is processed based on rules and social norms, temporal sequencing, established organizational routines, and group action such as problem solving and decision-making. Rather than generating knowledge, Grant asserts that the primary role of the firm is to facilitate in the integration of individual knowledge into products and services. His emphasis is on the employee as the principal actor in organizational knowledge, with the implication that the firm's organizational structures should delegate authority towards the individual.

Brown and Duguid[35] also expand upon the idea of Grant's knowledge-based firm, arguing that communal interactions are critical in the development of knowledge. Beyond the individual learner, knowledge is produced and held collectively in "communities of practice", where collaboration and discussion are the essential activities for developing knowledge and common understanding between members. The boundaries of these communities of practice are informal, and can extend well beyond the walls of an individual firm. Their viewpoint emphasizes the social nature of knowledge development and the need for social strategies for promoting knowledge transfer, including the importance of boundary objects and knowledge translators in facilitating this knowledge exchange.

### *2.5.3. Knowledge Management*

Along with the work of Bohn, Grant, Brown, and Duguid, there has been the recent meteoric growth of the "knowledge management" movement. Today, it seems as if there is almost universal interest in the role that knowledge plays in organizations. Like birds of a feather, knowledge management and intellectual capital are closely interrelated topics. Simply put, knowledge management tries to identify and manage a firm's intellectual capital, with the goal of maximizing returns on these knowledge-based assets. Although all firms have intellectual capital, many are only starting to develop formal knowledge management efforts to oversee their assets.

Like the topic of corporate knowledge, there is a wealth of literature that defines what knowledge management is, and how it can be implemented in the workplace. Some of the researchers in the knowledge management field, such as Davenport and Prusak[36], provide useful methods for

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[34] Grant, Robert M. "Toward a Knowledge-Based Theory of the Firm", *Strategic Management Journal*, Vol.17, 1996, pp109-122.

[35] Brown, John Seely and Duguid, Paul, "Organizational Learning and Communities of Practice: toward a unified view of working, learning and innovation", *Organization Science*, 1 n. 1, 40-47. See also Brown and Duguid, "Organizing Knowledge", *California Management Review*, Vol.40 No.3, Spring 1998, pp.90-111, and Brown and Duguid, *The Social Life of Information*, Harvard Business School Press, Boston, 2000.

[36] Davenport, Thomas H., and Prusak, Laurence, *Working Knowledge: How Organizations Manage What They Know*, Harvard Business School Press, 1997.

differentiating between types of knowledge in the firm. Importantly, they offer insights about how knowledge-based assets are transferred throughout the organization, making a distinction between accessing, generating, embedding, and transferring knowledge within the firm.

Many of today's knowledge management efforts, however, focus primarily on the measurement, cataloging, and storing of knowledge. These efforts may best be described as "knowledge accounting" – with an emphasis on knowledge stocks and the development of systems or tools for capturing them in corporate databases. With the emergence of the movement, researchers and managers have struggled with the first step in the process – the so-called "measurement problem".

### *2.6. Attempts at Measuring Intellectual Capital*

As mentioned earlier, the measurement problem is driven by the assertion that "what cannot be measured, cannot be managed." When trying to develop metrics for intellectual capital, the majority of researchers and managers frame the issue by extending the accounting metaphor: namely, that knowledge-based assets can be measured and managed similar to tangible assets.

This framing of the issue – to develop "intellectual capital accounting" methods – places an emphasis on the quantitative assessment and valuation of intellectual capital assets. At its simplest level, many researchers and financial analysts rely on the market-based evaluation of intellectual assets – assessing the difference between market and book values – and attempt to estimate the return on investment for a company's intangible assets. Others have attempted a more detailed accounting of knowledge-based assets, broken down by categories, and valued using pre-established standards. Although this task can seem daunting, a number of methodologies and guidelines have been developed over the years to aid in this task.

For example, human resource accounting (HRA) has existed for a number of years and has achieved a limited degree of acceptance in the CPA community. HRA, as summarized by Flamholtz[37], attempts to value human capital by evaluating the costs associated with the human resource function. This includes the cost of recruitment, the original value of the human capital, the replacement cost of human resources, and any costs associated with termination. The original value represents the cumulative sum of all educational and training costs for the skills that the employee embodies. Although this method attempts to achieve a rigorous valuation, it tends to ignore all forward-looking value, including an individual's potential for growth and development. Combined with the moral dilemma of assessing human value, HRA techniques do not always resonate with many corporate managers.

The valuation of R&D expenditures offers another example of an attempt at intangible asset accounting. For example, Hirschey and Weygandt[38] outline an approach to estimate the value of

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[37]Flamholtz, Eric G. *Human Resource Accounting,* San Francisco: Josey-Bass, 1985

[38]Hirschey, Mark and Weygandt, Jerry. "Amortization Policy for Advertising and R&D Expenditures", *J. Accounting Research,* Vol.23 No. 1, Spring 1985, pp.326-335.

R&D programs based on investment to date and perceived market value of the project. Classical accounting approaches, such as using estimation techniques and amortization methods, are incorporated into the valuation process. Using similar techniques, Rennie[39] develops an example of a firm's balance sheet for R&D projects and patent expenditures, estimating future cash flows and the return on investment.

A number of today's intellectual capital researchers have followed a similar vein in their attempts at intellectual capital accounting. Lev[40] [28] develops a "knowledge capital scoreboard" which measures various project costs and R&D expenditures. These financials are then benchmarked against expected returns on intangibles by subtracting out all tangible and financial earnings, leaving only the contribution of intangible knowledge assets as a portion of corporate earnings. Lev has applied this technique to 20 pharmaceuticals and 27 chemical companies to develop a first-cut assessment of the percentage of earnings due to knowledge assets. Strassmann[41] has also developed comparative knowledge capital rankings, based initially on subtracting the costs of financial capital from firm profits. Strassman uses this technique to calculate an effective yield that is realized on by a firm's intellectual capital, which he describes as the "knowledge value-added" from assets not on the firm's balance sheet. Based on this yield, he uses an estimate of the firm's cost of capital to determine the principle value of the underlying intellectual assets.

Finally, other researchers have attempted to develop detailed, "line item by line item" balance sheets for a firm's intellectual capital. Clare and Detore[42]offer a detailed valuation methodology, extending conventional valuation methods to pricing investments in human capital, intellectual property, work processes, and the resulting knowledge-based products and services. Using a survey approach, Van Buren and Bassi[43] of the American Society for Training and Development (ASTD) are attempting to extract meaningful metrics for intellectual capital. Based on data from a working group of companies, they hope to operationalize different aspects of human capital, structural capital, and customer capital and track changes in their stocks over time. To support these metrics, a set of financial measures will be recorded to extract correlations between intellectual stock changes and firm "effectiveness" (in the form of profitability). Reilly and Schweihs[44] are also developing a comprehensive method for intellectual capital valuation. Based

[39]Rennie, Morina. "Accounting for knowledge assets: do we need a new financial statement?", *Int. J. Technology Management*, Vol.18 No.5/6/7/8, 1999, pp.648-657

[40] Lev, Baruch, *Intangibles: Management, Measurement, and Reporting*, Brookings Institute, 2001. See also Mintz, S.L. and Lev, "Seeing is Believing", *CFO Magazine*, February 1999, and its follow-up article, "The Second Annual Knowledge Capital Scoreboard", *CFO Magazine*, February 1, 2000.

[41] Strassmann, Paul A., "Calculating Knowledge Capital", *Knowledge Management Magazine*, October 1999. Strassman also applies these methods to compare U.S. industries *in Information Productivity: Assessing Information Management Costs of U. S. Corporations*, Information Economics Press, 1999.

[42] Clare, Mark K., and Detore, Arthur W., *Knowledge Assets Professional's Guide to Valuation and Financial Management*, Harcourt Brace, 2000.

[43] See Van Buren, Mark E., "A Yardstick for Knowledge Management", *Training and Development*, May 1999, and Van Buren and Bassi, Laurie J. "Valuing investments in Intellectual Capital", *Int. J. Technology Management*, Vol.18 No.5/6/7/8, 1999, pp.414-432.

[44] Reilly, Robert F. and Schweihs, Robert, *Valuing Intangible Assets*, McGraw Hill, 1999.

on their CPA experience, they attempt to categorize all assets as real estate, tangible personal property, intangible real property, or intangible personal property. Specific guidelines are described for appraising each property type, and estimates can be made of asset operational life cycle and depreciation. Although rigorous in nature, these attempts at quantifying intangible assets, however, do not contribute to developing a conceptual framework for understanding intellectual capital, nor provide any operational insights about the management of a firm's knowledge-based assets.

## 2.7. *Remaining Questions for Intellectual Capital Research*

### 2.7.1. *Shortcomings of Prior Research*

These attempts at intellectual capital accounting, along with the analytical foundations from prior research, provide a good starting point for understanding the role of knowledge in the firm. Unfortunately, by taking a classical accounting approach to assigning value to intellectual capital, I'll argue that some researchers have made two mistakes. First, they have underestimated the magnitude of the task of trying measure and value intellectual capital. Second, their efforts often do not result in meaningful data for managers and practitioners to use. Their aftermath, regrettably, may be the bittersweet fruits of hard labor.

As seen in these valuation methodologies above, many researchers rely either on market indicators or internal accounting techniques to quantify intellectual assets and assign a dollar value to them. Both approaches, using either external or internal measures, face serious limitations due to the troublesome nature of intangible assets. First, the majority of these researchers rely on the external, market evaluations such as market-to-book ratios to extrapolate the value of the underlying intellectual assets. This methodology assumes that the market has sufficient information to value a company's intellectual capital. It's also based on the assumption that the market is the most accurate assessor of financial value.

From a free-market economist's point of view, the market valuation is the truest indicator of firm value and, given perfect information and frictionless transactions, it correctly evaluates the sum of a firm's tangible and intangible assets. From an academic viewpoint, however, market-based assessments leave much to be desired. Deference to the all-knowing power of the market may be a pragmatic approach to valuation, but, for knowledge-based assets, it is unsatisfying from a conceptual point of view.

Clearly, without publicly available data on corporate knowledge-based assets, it is virtually impossible to fairly assess a company's intellectual capital. Do companies have knowledge assets that are about to revolutionize their market, but have yet to realize their value? Rather than account for the value of the underlying intellectual assets, market value usually represents only a rough extrapolation of value based on conventional financial measures, past performance, and vague perceptions about future business. Another fly in the ointment: market valuation of intellectual capital rests on the assumption that Wall Street subscribes exclusively to a resource-based view of firm competitiveness. What if the difference between market and book value is not solely dictated by a company's knowledge-based assets, but rather is influenced by supply and demand? If market forces are responsible for the difference between a firm's book value and market value, then it fails to be a good indicator of the value of intellectual capital. A clearer understanding of the link between knowledge-based assets and value, and how these causal connections vary across firms and business sectors, is needed.

For researchers who try to develop line-item measures of internal assets, the process is frustrated by the tangible bias of conventional accounting systems and the lack of detailed data on intangibles. Many conventional reporting structures – such as the lack of detailed breakdown of overhead labor expenses – fail to capture the necessary detail to connect expenditures on human capital to long-term value creation. Causality is difficult, as accounting systems rarely correlate the investments in human capital and R&D with the project-specific value that these investments create. Although some researchers have made progress on calculating ROI for employee training programs, this represents only a small portion of a company's investment in its human, structural, and relational capital. Understandably, most managers are frightened off by the magnitude of the task.

In reality, the accounting approach to intellectual capital is not only laborious, but misses the point. Accumulation of knowledge for knowledge's sake, combined with attempts to catalog and value these assets, does not provide what managers need – a connection to value, the kind that managers can apply to their operational and strategic needs.

To respond to these needs, the "balanced scorecard" approach has emerged as a useful tool for developing non-conventional performance measures. The most notable example is the balanced scorecard first developed by Kaplan and Norton[45] in 1992 and refined in later publications[46]. Kaplan and Norton's methodology identifies metrics in the four areas: financial measures, customer perspective, internal firm goals, and growth opportunities. By moving away from standard financial reporting methods, their balanced scorecard serves as a guideline for helping managers identify unconventional metrics, many of which are linked to intellectual capital. Importantly, these metrics are, by design, linked to the operational and strategic goals of the company and result in a meaningful tool for managers. Efforts by other researchers, including Edvinsson and Roos & Roos, have paralleled the "balanced scorecard" approach by developing lists of non-financial measures.

Although these scorecards serve as a good lens for managers to examine their company's non-financial performance, they are similar to a recipe – they tell managers what to do, but not why. It is true that Kaplan and Norton's list of topics – financial, customer perspective, internal firm goals, and growth opportunities – highlights areas that managers often ignore. But it doesn't

[45] Kaplan, Robert S. and Norton, David P., "The Balanced Scorecard", *Harvard Business Review*, Jan-Feb. 1992, pp.71-79.

[46] See Kaplan and Norton, "Putting the Balanced Scorecard to Work", *Harvard Business Review*, Sep-Oct. 1993, pp.134-147, "Linking the Balanced Scorecard to Strategy", *California Management Review*, Vol.39 No.1, Fall 1996, pp.53-79.

provide a framework for understanding how knowledge is created, transferred, and transformed in an organization. Nor does it explain how knowledge-based assets are connected to value creation. Although the balanced scorecard includes aspects of human, structural, and relational capital, it is not tied to a strong conceptual framework for understanding knowledge in the firm.

### *2.7.2. Proposed Areas for Research*

Despite the wealth of research on knowledge in the firm, a number of areas remain where the literature has raised deep, unanswered questions. First, an improved framework is needed for understanding intellectual capital, one that provides useful insights about knowledge-based assets and their connection to value creation. This understanding could be used by managers to exploit their firm's intellectual capital – what it is, where it is, how it's used, and just importantly, where it's missing. By exploring the role that human, structural, and relational capital plays in value creation, it should be possible to develop a "balanced" approach that explains the dynamic process of knowledge transformation in firms.

It's important to underscore the dynamic nature of a new model for intellectual capital. Prior research, including efforts at asset accounting, have tended to emphasize "stocks" of knowledge, with few insights about how these stocks are utilized. Fahey and Prusak[47] have noted that there is a tendency in the literature to develop balance sheets that measure intellectual capital "stocks", with little attention to the "flows" of intellectual capital within a firm. In particular, the balance sheet approaches tend to de-emphasize the flow mechanisms between knowledge stocks and the intervening variables that control their flows. A complete framework should try to explain these flows – how knowledge is created, transformed, and lost – as well as explain the role of these flows in value creation. A central claim of this work is that the static nature of previous framings is precisely the reason for their failure to unambiguously link intellectual capital to value creation.

A dynamic framework of intellectual capital also lends itself to a better understanding of the organizational processes that shape these knowledge stocks and flows. Despite the acknowledgement that intellectual capital and organizational processes are intimately tied together, there are few examples of prior work that explicitly investigate the connections between intellectual capital and organizational theory. The bottom line is that the management of intellectual capital is a broad, complex issue that must be considered within the organizational and industrial context of each firm. Although this point has not been ignored, it hasn't been thoroughly explored, either. All too often, the pearls of wisdom gained from research in intellectual capital, knowledge management, and organizational theory remain scattered and disjointed from one other. A clear framework is one that dynamically associates a firm's intellectual capital assets with its organizational processes.

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[47] Fahey, Liam and Prusak, Laurence, "The Eleven Deadliest Sins of Knowledge Management", *California Management Review*, Vol.40 No.3, Spring 1998, pp.265-276.

What are the requirements for such a framework? First, it should integrate the concept of intellectual capital with flows of knowledge at various levels throughout the firm. It should address organizational norms and processes – including the dynamics of communication, consensus building, and coordinated collective action – that shape the development of a firm's knowledge-based assets. The model for the framework should include learning phenomena within the organization, as well as learning via actors external to its boundary. And the framework should identify the control mechanisms for knowledge flows, or at its very least, address which flows can be influenced and controlled by managers, and which cannot.

With these requirements in mind, the next chapter explores a new framework for understanding intellectual capital – one that attempts to draw connections between human, structural, and relational capital in the firm. Through this "mental model" of intellectual capital, I hope to instill some new, dynamic meaning into these formerly static categories of knowledge assets. The framework also provides the basis the rest of this research, including the aerospace industry case studies. The ultimate goal is to provide managers with a better understanding of knowledge assets in the firm, the interplay between these various forms of intellectual capital, the organizational context for knowledge transformation, and most importantly the role of these assets in value creation.

## 3. Conceptual Framework

### *3.1. A Framework for Understanding Intellectual Capital*

By developing the concept of intellectual capital, previous researchers have heightened our awareness of knowledge-based assets and their potential for creating value. Now that we know what human, structural, and relational capital is, we need to know what to do with them.

As a first step, we need to understand how these assets are both transferred and transformed in product development projects. In this chapter, a framework, or "mental model" is developed to aid in our understanding of the dynamic nature of intellectual capital. Building on prior research, the model characterizes knowledge and organizational learning as the "stocks" and "flows" of intellectual capital. Rather than simply looking at knowledge-based assets and trying to quantify them, the framework provides some insights into how intellectual capital evolves – via creation, transference, and transformation – in a dynamic process that creates value along the way.

Given that intangible assets are constantly changing and hard to define, an understanding of the dynamic nature of intellectual capital is essential for both identifying and applying these hidden resources. Based on this conceptual understanding, we can also begin to make some hypotheses about these dynamic processes, their timescales, and the right "mix" of ingredients needed for successful product development. In addition to laying the groundwork for the rest of the research, this coherent mental model will hopefully allow managers to realize the full potential of their firm's skills and knowledge-based assets.

### *3.2. Stocks, Flows, and Organizational Learning*

Although the different taxonomies from the literature review attempt to categorize intellectual assets, they provide little guidance or insight to business managers. The intangible nature of intellectual capital is partially to blame – as noted by Stewart[48], knowledge-based assets have a "fuzzy" quality that makes them difficult to define, understand, and most importantly, apply to solving a firm's problems. However, one of the shortcomings of these taxonomies is that they fail to explain how these assets are created and transformed by organizational processes, nor how they are used to create value. Often, they are treated as inanimate stocks of knowledge, without any "mental model" to explain how they develop and evolve over the course of multiple projects. Using terminology from the field of system dynamics[49], an operationalized understanding of intellectual capital requires both "stocks" of knowledge and "flows" that dynamically explain how knowledge is accumulated, transferred, and transformed over many product development cycles.

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[48] Stewart, Thomas A., *Intellectual Capital*, Currency Doubleday, 1997

[49] See Forrester, J. W., *Industrial Dynamics*, M.I.T. Press, 1961, or Sterman, John D., *Business Dynamics: Systems Thinking and Modeling for a Complex World*, McGraw-Hill, 2000.

These flow mechanisms are often neglected by researchers who emphasize the financial valuation of intellectual capital stocks. As pointed out by Fahey and Prusak[50], there is a tendency to create Intellectual Capital (IC) "balance sheets" that attempt to measure IC stocks to the detriment of IC flows. These flows are important constructs for the following reasons.

### *3.2.1. The importance of flows in a dynamic model*

Without flows, there is a tendency to think of intellectual capital as a static resource. I argue that this de-emphasizes the dynamic nature of knowledge within the firm, and does not promote a coherent mental model of intellectual capital that aids in understanding the product development process. Although the categories of human capital, structural capital, and relational capital help us identify and distinguish between different knowledge-based assets, it is only a partial explanation of intellectual capital and its role in the firm.

It's not just the stocks of intellectual capital that are important – it's what firms do with them. In particular, firms today must rapidly respond to market opportunities, and need to be able to use their intellectual assets to create new products. This ability for managers to quickly leverage their intellectual capital is what Teece refers to as the "dynamic capabilities" of firms[51]. Static framings of intellectual capital are missing this temporal component, as they have no mechanisms that describe how knowledge is captured, created, and applied towards new product development.

### *3.2.2. Flows as a representation of Organizational Learning*

Flows are a vital component of the framework since they represent the critical processes of knowledge transfer and organizational learning in the firm. This is the missing piece in many formulations of intellectual capital, as the frameworks lack a mechanism for the creation, growth, and potential decline of their intellectual capital assets. Organizational learning, therefore, needs to be explicitly included in these models.

The topic of organizational learning has received considerable attention over the last decade from both researchers and practitioners. Peter Senge's work on the learning organization has been foremost in this field[52]. In his descriptions of learning organizations, Senge frequently uses the stock & flow analogies from systems dynamics to capture the integrated nature of learning by individuals and organizations[53].

A complete framework of intellectual capital should include flow mechanisms that represent the different ways for this organizational learning to occur. Organizations "learn" as staff members acquire new knowledge assets through observation, experiences, and discovery. As pointed out

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[50] Fahey, Liam and Prusak, Laurence, "The Eleven Deadliest Sins of Knowledge Management", *California Management Review*, Vol.40 No.3, Spring 1998, pp.265-276.

[51] Teece, D. "Capturing Value from Knowledge Assets: The New Economy, Markets for Know-How, and Intangible Assets", *California Management Review*, v.40-3, 1998

[52] Senge, P., *The Fifth Discipline: The Art and Practice of the Learning Organization*, New York: Doubleday, 1994.

[53] In particular, see Senge, "Organizational Learning: A New Challenge for System Dynamics", Working Paper D-4023, Sloan School of Management, MIT, 1989.

by Argyis and Schon, organizational learning is an anthropomorphism: it is not "organizations" that truly learn, but the people who are members of that organization[54]. These learning flows originate with the human capital of the firm, and should portray that staff members construct both individual and shared meaning with colleagues in their firm. The flows should also represent how individuals convert tacit knowledge to explicit knowledge, thereby capturing and codifying knowledge into tools, processes, and procedures. Finally, the flows should represent how knowledge is acquired through interactions and relationships with external actors – including clients, suppliers, industry counterparts, and financial stakeholders – and incorporated into the corporate stocks of knowledge. In his description of organizational learning, Huber categorizes these processes as knowledge acquisition, information distribution, information interpretation, and organizational memory[55].

A rigorous framework of intellectual capital should address these flows of knowledge – both into and within the firm – with simple mechanisms that capture the nature of Huber's constructs. However, characterizing these flow mechanisms and the valves that control them is difficult, given the intangible and complex nature of knowledge transfer and organizational learning.

#### *3.2.3. The role of IC flows in value creation*

Finally, the flows represent a critical aspect of intellectual capital since they are often responsible for value creation for the firm. Although intellectual capital holdings have the potential to create value, it is in their application – when knowledge is leveraged to create new products and new services – that value is often generated for a firm and its clients. This assertion is especially true for the product development cycle with its emphasis on creativity and innovation. As a static corporate holding, knowledge stocks have little value of their own; they are valuable when applied to problem solving and product creation. The staff of a product development team (Drucker's so-called "knowledge workers") creates value through the application of intellectual capital stocks, in a process where knowledge is not simply transferred but is modified, augmented, and transformed into new knowledge assets for the firm. Since they are intimately tied to value creation, the flows of organizational learning are the most important portion of the intellectual capital framework for managers to understand, as they provide the "dynamic capability" to rapidly create knowledge and deliver value. Senge even predicts that "the rate at which organizations learn may become the only sustainable source of competitive advantage".[56]

### *3.3. A Conceptual Framework of Intellectual Capital*

What managers and researchers often need is a simple framework – one that aids in the formation of a coherent mental model of resources and capabilities within the firm. At a minimum, a framework for intellectual capital should:

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[54] Argyris, C., & Schon, D.A., *Organizational learning: A theory of action perspective*, Reading, MA: Addison-Wesley, 1978.
[55] See Huber, G.P. "Organizational learning: The contributing processes and the literatures", *Organization Science*, 2/1:88-115, 1991.
[56] Senge, P.M., "The leader's new work: Building learning organizations", *Sloan Management Review*, Fall: 7-23, 1990

- Define what intellectual capital is, and what it isn't
- Include mechanisms for intellectual capital creation, transfer, and loss
- Frame the topic by providing insights about intellectual capital's use in a business enterprise

A new framework for understanding intellectual capital, derived from a stock-and-flow model of the three categories of intellectual capital, is summarized by Figure 3-1. Its goal is to create a dynamic mental model of how organizational learning contributes to a firm's intellectual capital, and how these intangible assets change over time.

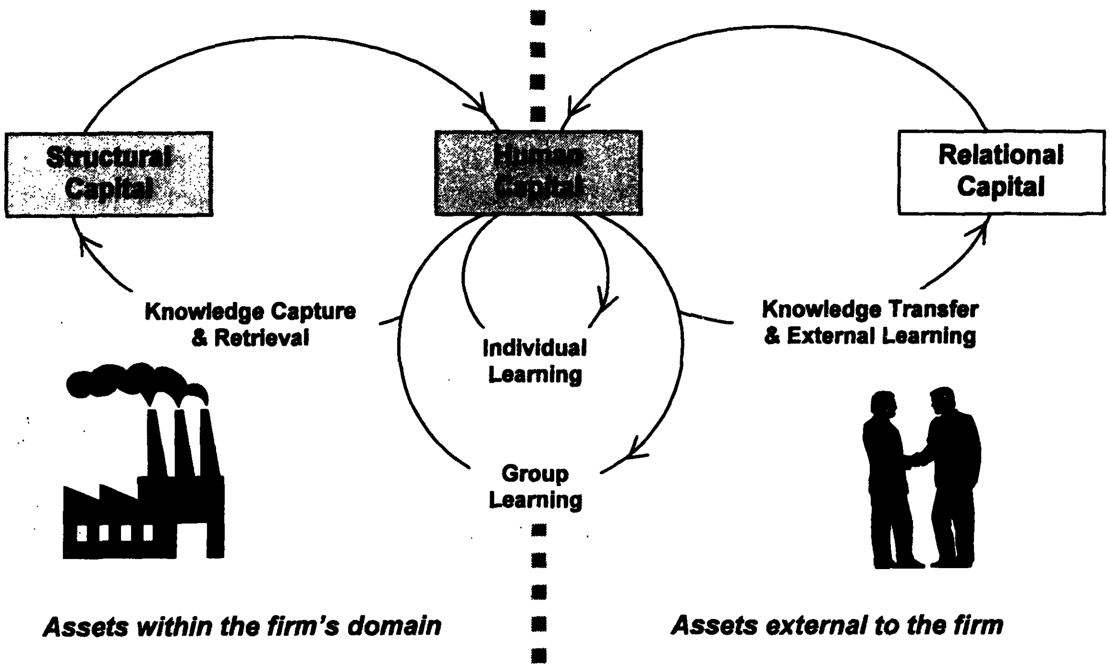


**Figure 3-1 – A framework for understanding intellectual capital**

The intellectual capital that a company possesses consists of "stocks" of human, structural, and relational capital. The arrows in the figure indicate the "flows" – different types of organizational learning – that contribute to a firm's intellectual capital stocks. The figure is divided down the center by a line, which denotes the boundary of the firm with the outside world. The structural capital on the left half represents the explicit knowledge, captured and owned by the firm, which falls within the firm's domain. On the right half, the firm's relational capital with clients, partners, and suppliers lies outside of the boundary and, accordingly, is not wholly controlled by the firm. Human capital is positioned in the middle of the framework, both literally and metaphorically. It plays a central role in the flow of all knowledge assets, serving as the vehicle for organizational learning, knowledge transformation, and the creation of both structural and relational capital for the firm. Appropriately, all organizational learning flows in the figure pass through the firm's human capital.

In a strict sense, the figure violates one of the principles of stock-and-flow diagrams in system dynamics: the conservation of assets. Normally, any flow of assets out of a box would reduce the quantity of the stock. However, since knowledge is not a tangible asset, it need not obey the laws of conservation. Instead, knowledge-based assets are more like processes, where flows may not decrease the original stock, but may actually augment them. In fact, one of the powerful characteristics of intellectual capital is its limitless potential to be applied to create value without exhaustion, as evidenced by the near-zero marginal cost of computer software after it has been developed.[57] Flows, therefore, do not ordinarily diminish the originating IC stock, but instead represent processes where new forms of intellectual capital are created as knowledge is transformed.

The flows in the framework represent four organizational learning "loops" that contribute to generating knowledge-based assets for the firm. Central to the conceptualization is the learning that occurs at the individual and group levels of the firm. Enabled by the human, structural, and relational capital of the firm, individual learning serves as the fundamental process for knowledge creation. "Group learning" recognizes a higher level of learning, where colleagues construct shared meaning in a collaborative setting. During this collaborative process, knowledge is transferred, modified, and often "transformed" across specialized domains through the use of boundary objects that aid in developing shared meaning[58]. This transformation also requires the creation of new knowledge that supports understanding and helps build consensus viewpoints about the shared knowledge[59]. As pointed out by a number of authors, this group learning process is synergistic in nature, creating greater knowledge for the firm than the sum of the individual contributions.

The concept of "group learning" has similarities to existing organizational theories, including the concepts of "ba" and "communities of practice". Nonaka, Toyama, and Konno emphasize that knowledge creation takes place in a shared context, called "ba" (which roughly means "place"), that forms an interactive environment that spans individual knowledge boundaries[60]. Project teams work within this shared context, which can be thought of as the organizational culture in which knowledge creation takes place.

In addition, the "group learning" in this framework represents "communities of practice" that form both within and outside of a firm[61]. Since many communities of practice extend beyond the boundaries of the firm, they serve as a means to transfer knowledge into the firm and build relationships that foster understanding. The flows of "knowledge transfer" and "external

[57] Most IC researchers have affirmed the importance of knowledge as a non-rival, non-scarce good. See Romer, Paul M., "Endogenous Technological Change," *Journal of Political Economy*, October 1990, 98 (5), S71–S102 for a seminal reference.)
[58] Carlile, P., "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development", *Organizational Science*, 2002.
[59] Carlile, P. and Rebentisch, E., "Into the Black Box: The Knowledge Transformation Cycle", forthcoming.
[60] Nonaka, I., Toyama, R., Konno, N., "SECI, Ba, and Leadership: a Unified Model of Dynamic Knowledge Creation", *Long Range Planning* 33, 5-34, 2000.
[61] Brown, J.S., & Duguid, P., Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation, *Organization Science*, 2/1: 40-57, 1991.

learning" are meant to capture the organizational learning mechanisms that extend outside the firm, as they not only acquire knowledge but build new relational capital for the firm.

Finally, the flows of "knowledge capture" and "knowledge retrieval" represent the mechanism for storage and retrieval of organizational knowledge. These processes create and draw upon a firm's structural capital, as knowledge from individual, group, and relational learning processes are captured and codified in what Huber refers to as "organizational memory". These flows to and from the firm's structural capital involve the tacit-to-explicit-to-tacit cyclical conversion of knowledge[62].. As knowledge is codified, it is converted from tacit to explicit; when retrieved, it is converted back from explicit to tacit. The structural capital that is created by this cyclical process – embodied in firm's documents, databases, tools, artifacts, and procedures – represents the form of intellectual capital in this framework that is most clearly owned and controlled by the managers of a firm.

### *3.4. Constructs from the IC framework*

There are a number of characteristics of this framework that can provide managers with useful insights about their firm's intellectual capital:

#### *3.4.1. The central role of Human Capital*

As mentioned above, the framework emphasizes the central role of human capital in intellectual capital growth and acquisition. Simply put, human capital is the most important intellectual asset that a firm possesses. The knowledge, experience, and creative capabilities of both staff and management are not only essential for profits, but are also required for the creation of structural and relational capital for the firm. All organizational learning and knowledge transfer at the firm depends on its underlying stock of human capital and their ability to design, innovate, make tacit knowledge explicit, develop formalized tools and corporate processes, and establish relationships with counterparts outside of the firm. Understanding the human aspect of knowledge and the theories behind individual learning is therefore a necessary step in improving organizational performance[63]. Accordingly, all flow mechanisms in the diagram pass through the firm's human capital resources. This construction confirms human capital's role as the primary source of intellectual capital development in the firm, making it a necessary (but not sufficient) condition for project success.

#### *3.4.2. The degree of control of a firm's assets*

One of the other features of this framework is that is serves as a bridge between earlier IC formulations (Sveiby, Roos, Edvinson) and the recent findings of the Brookings Task Force on Intangibles.[64] In their investigation of the economic role of intangible assets and the difficulties

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[62] See Nonaka, I., "The Knowledge-Creating Company", *Harvard Business Review*, Nov-Dec 96-104, 1991.
[63] Kim, D. H., "The link between individual and organizational learning", *Sloan Management Review*, 35(1), 37-50, 1993.
[64] Blair, M. and Wallman, S. "Unseen Wealth: Report of the Brookings Task Force on Intangibles", Brookings Institute, D.C., 2001.

in developing accounting standards to measure them, the task force developed three categories of knowledge-based assets:

- Assets that can be owned and sold
- Assets that can be controlled, but not separated out and sold
- Intangibles that may not be wholly controlled by the firm

In their report, the panel recommended support for a public-private partnership to define useful reporting models for these loosely-controlled intangible assets. By delineating the firm's domain, the framework graphically indicates how the firm's degree of control varies. Assets that are clearly controlled by the firm, such as intellectual property, codified corporate processes, and trade secrets, are types of structural capital which fall on the left half of the figure. Towards the right half of the figure, the firm's ability to control its intellectual assets erodes, with relational capital assets – including networks of business relationships – exhibiting the least degree of control. Human capital, straddling the border between the firm and the outside world, is positioned to emphasize that it is a fleeting intangible asset that, at best, is only partially owned and controlled by a firm. Therefore, the framework not only defines IC stocks and organizational learning flows, but incorporates degrees of control over these assets.

#### *3.4.3. Clockspeeds for IC development*

By creating a dynamic model of intellectual capital, the framework can also provide insights about how these stocks and flows vary over time. For example, three theories about the dynamic nature of intellectual capital are that:

- Stocks of human, structural, and relational capital develop over different time periods. Borrowing terminology from Charles Fine, each organizational learning loop operates at a different "clockspeed", requiring different timescales to accumulate the three types of intellectual capital.
- IC stocks can also have a "shelf life", emphasizing that intellectual capital is comprised of perishable assets that lose their relevancy – and their ability to create value – over time.
- Product development projects may require different balances of human, structural, and relational capital over the course of the project. In other words, some types of intellectual capital may contribute more to value creation than others, and that the required mix can change throughout product development.

Figure 3-2 illustrates how the learning and knowledge transfer flows in each loop can occur at different speeds:

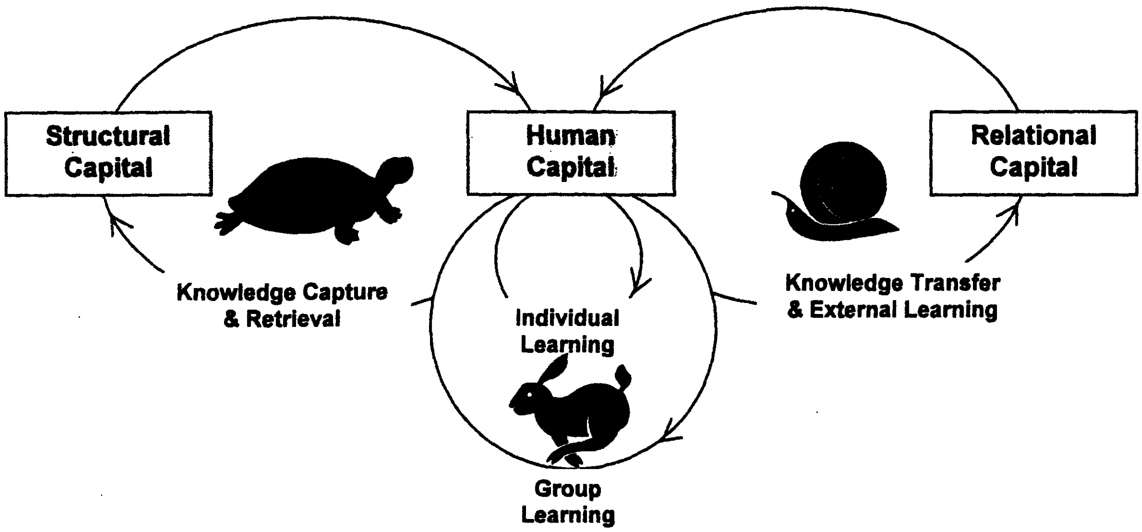


**Figure 3-2 – Clockspeeds for intellectual capital development**

Elaborating on this figure, I'll argue that human capital can be more rapidly accumulated than either structural or relational capital. This is not to say that humans, e.g. new staff, can be quickly hired and incorporated into a design group. Rather, a company's human capital improves as its people collect data, learn about new disciplines, and develop new capabilities that benefit the firm. As staff members learn and assimilate new knowledge, human capital development can occur rapidly at the individual level. In addition, working groups can quickly share ideas and mental models that aid in understanding and solving new problems, developing more human capital through the group learning loop. In contrast, structural capital takes more time to develop as knowledge must be made explicit and codified in the form of documents, databases, procedures, and organizational processes. In most cases, these assets are created over the course of many product design cycles and multiple projects, often requiring months-to-years to develop.

Relational capital – especially if it has lasting value – can take even longer to develop, as organizational boundaries must be spanned and relationships must be built, based on mutual trust and a track record of past performance. Organizational resistance to change can also prolong the process of building new relationships and altering corporate procedures. The long lead times that are needed to develop structural and relational assets suggest that managers need to:

- Understand the concept of intellectual capital and be able to identify its various forms,
- Be able to assess their quality of their current IC stocks and project their future needs, and
- Plan ahead to allow sufficient time for needed IC development

### *3.4.4. The shelf life of IC assets*

A dynamic model of intellectual capital should also accommodate mechanisms for the loss of intellectual capital. Just as tangible assets depreciate over time, intellectual assets can lose their value when knowledge becomes outdated, when staff members leave, relationships erode, or when accumulated knowledge is no longer relevant to the firm's mission. This last point emphasizes that "knowledge for knowledge's sake" is not intellectual capital. An underlying assumption of the framework is that knowledge-based assets have worth only if they can be applied (or have the potential to be applied someday) towards the creation of value for the firm and its clients. For example, accumulated design data from heritage programs is a form of corporate knowledge, but if these documents or databases are no longer accessible, then they do not add value. Similarly, a firm's intellectual capital can be considered to be perishable assets that decrease in value as their usefulness or relevancy diminishes.

In the preface to his revised edition, Stewart draws an analogy between intellectual assets and a firm's inventory of tangible assets, asserting that accumulations of both assets can depreciate over time[65]. As design tools and old technologies become outmoded or obsolete, skill sets become outdated, or relationships with suppliers erode, a firm's base of intellectual capital diminishes. For projects that involve new product development, the "shelf life" of a firm's intellectual capital becomes particularly important, since designers must have up-to-date knowledge and understanding of the latest technologies when developing new products. Given the rapid pace of technological change today, heritage design data can quickly become irrelevant. It may also be that conceptual or "general information" about systems has a longer shelf life than detailed, "specific information" that is technology-specific and more likely to become obsolete.[66] Using case studies of projects with varying degrees of development, this research will investigate the lifespan of intellectual capital, in an effort to identify which types of intellectual assets create lasting value and provide extended capabilities for product development projects.

### *3.4.5. A balanced approach to intellectual capital in product development*

Finally, the stock-and-flow framework shows that the categories of intellectual capital are interdependent, requiring managers to consider whether they have the right "mix" of human, structural, and relational capital to execute new projects. In addition, each type of intellectual capital may take on added importance during different phases of the product development cycle. For example, structural capital – in the form of codified knowledge, tools, and processes – can take on added importance during the preliminary and detailed design phases, when heritage designs and collaborative tools become essential to the design process. Relational capital assets may assume a greater role during the early business acquisition phase, as managers try to identify potential clients, create value propositions, and develop project requirements and specifications that are aligned with the client's needs.

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[65] Stewart, Thomas A., *Intellectual Capital*, Currency Doubleday, 1997.

[66] These categories are derived from a study of technology transfer and knowledge flows in a corporate joint venture; see Rebentisch, E., "Knowledge in Flux", MIT PhD dissertation, 1995.

The framework suggests that a balanced approach to IC assets may be needed for successful product development. In addition, managers that can draw upon a balanced allocation of intellectual resources may be able to benefit from synergistic capabilities that provide competitive advantages. If the various forms of intellectual capital truly work in concert, then competitors would face a substantial barrier in trying to replicate a broad combination of human, structural, and relational assets. Likewise, projects that are missing one aspect of intellectual capital may fail, even with superior intellectual assets in other areas. Stagnation in one branch of the framework can be destabilizing to the entire enterprise; for example, firms that fail to develop new relational capital may become locked into their client base, miss new opportunities for business development, and become vulnerable to either disruptive technologies or market erosion[67]. The framework suggests that managers not only need to measure their intellectual capital, but must consider whether the correct balances of assets are allocated during different stages of the product development.

### *3.5. Questions posed by the IC framework*

In summary, the framework presented here builds on the three categories of intellectual capital by establishing boundaries, domains of control, and dynamic flow mechanisms for knowledge transfer and organizational learning. The new framework hopefully advances the study of intellectual capital by creating a simple model – one that incorporates the dynamic nature of a firm's knowledge-based assets, provides constructs for intellectual capital development and obsolescence, and most importantly, connects intellectual capital to value creation.

Although the framework provides a structure for understanding intellectual capital, it is only a starting point. Theories about intellectual capital need to be either validated or disproved in the real-world. To this end, the research includes a number of case studies to investigate the role of intellectual capital in aerospace product development projects. With these case studies, we can address a number of the questions raised in the conceptual framework, including:

- How can intellectual capital stocks be measured, and which metrics are most meaningful?
- Likewise, how can intellectual capital flows be measured?
- Is a company's human capital the central, enabling component for fostering intellectual capital development?
- Do corporate managers have a lesser degree of control over their human and relational capital assets?
- Does a company's relational capital involve long lead times to develop?
- Is intellectual capital a perishable asset that depreciates with time?
- Which knowledge-based assets create lasting value, and which are fleeting?
- How can project managers develop the right balance of intellectual capital for their project?
- What combination of resources and capabilities leads to differentiated performance and maximum value creation?

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[67] For more on the concept of disruptive innovation, see Christensen, Clayton, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, 1997.

These questions can best be answered by studying a number of real-world cases in the aerospace industry. By selecting product development projects – especially the development of complex systems – we can investigate the tacit and explicit exchange of knowledge between design team members, managers, clients, and critical suppliers. Product development projects, therefore, are ideally suited for exploring the role of knowledge-based assets in firms. Hopefully, the best lessons about the true nature of intellectual capital can be learned from these knowledge-intensive projects.

# 4. Research Design

## *4.1. Introduction to Research Design*

The new framework of intellectual capital provides a structured method for thinking about knowledge-based assets in a firm. But is it correct? And if it is, how can it be practically used to manage these assets and create value?

One of the best ways to validate these concepts is to investigate how actual firms use their intellectual capital to develop new products and services. To bound the problem, the research looked strictly at product development efforts, despite the important role that intellectual assets plays in all aspects of business operations. Product development – with its emphasis on innovation, collaborative design, and coordination – provides rich examples about how knowledge assets are used to explore concepts, develop designs, and produce new products and services. Product development is therefore one of the most knowledge-intensive efforts for a firm, requiring managers to leverage different aspects of human, structural, and relational capital to successfully execute these projects.

With this in mind, the research looked at specific product development projects at a number of U.S. aerospace firms. Case studies were undertaken to explore how intellectual capital was created and utilized in these projects, including on-site visits and interviews of key staff members and senior management. This chapter summarizes some of the considerations behind this case study methodology, and details the techniques that were used to collect the data.

## *4.2. Criteria and level-of-analysis*

To research intellectual capital's role in the firm, seven aerospace projects were chosen for case study analysis. In part, these projects were selected because they involved the development of complex products or services in a technical setting. Complexity – in the form of advanced technologies (hard or soft) with interdependent subsystems – was a fundamental criterion for case selection. Most of these projects involved the incorporation of the latest cutting-edge technologies into complex systems, requiring state-of-the-art performance in a highly specialized application. These projects also required a systems-level approach to managing interfaces and performing trade-offs between inter-related subassemblies. Perhaps most importantly, these projects involve the tacit and explicit exchange of knowledge between members of large project teams, requiring managers to coordinate the efforts of varied functional specialists within the team.

Although the cases looked at complex aerospace projects, the important thread here is complexity, as opposed to strictly aerospace-related product development. Complexity – either in terms of new technologies, services, or programmatic and scheduling complexity – requires managers to coordinate all aspects of the enterprise to assure that all project goals are met. Aerospace is not alone in this regard; it's important to acknowledge that, in any industry, the success of highly complex projects hinges on coordination, knowledge transfer, and the norms and organizational culture in which they are developed. Although projects in aerospace firms typically involve high degrees of technological and programmatic complexity, my goal is that the results from this study can be generalized to other industries building highly complex products or providing highly complex services.

As for the level of analysis, each case study examined the performance of the project team striving to create a complex product. The level-of-analysis was chosen to be at the project team level for a number of reasons. First and foremost, a project team formed a bounded set of people and technical issues that could easily be studied. Although project outcomes are influenced by the entire organization in which they take place, corporate-level studies of all knowledge-based resources related to a project were considered too vast in scope to be manageable. At the risk of omitting important exogenous factors, a project-level analysis allows interviewees to focus on a distinct timeframe and particular details that were important to the product development. Clear boundary setting is also important to the collection of meaningful data, as the fuzzy, highly conceptual nature of intellectual capital can easily lead the research astray.

Finally, a project-level approach is appropriate for managers who are struggling with solving operational problems, where a change in their knowledge-based resource allocations can make a difference in project success. By choosing this level of analysis, the case study findings are more likely to lead to practical tools and insights that can guide these managers in their efforts.

### *4.3. Research questions and research design*

As mentioned above, the case studies focused only on product development projects. Although intellectual capital is involved in every aspect of the enterprise value stream, there is a critical reliance on existing intellectual assets during product development, as well as an urgency for developing new intellectual assets to spur innovation and growth. Researchers and practitioners alike must ask themselves this question: which of these knowledge-based resources and capabilities are essential for successful product development?

In this research, I propose to use the framework of intellectual capital as a "lens" to identify critical knowledge-based resources that are employed by product development teams – resources that are needed to innovate, leverage capabilities, and generate new profits. The theories outlined by the framework can be used to guide our case study research, helping us answer some essential questions, including:

- How do firms utilize their intellectual capital during product development?
- Which assets are crucial to promoting successful product development projects and creating lasting value for the firm?
- Are different intellectual capital assets needed during different phases of product development?

To address these questions, the case studies examine the role of intellectual capital during different stages of the product development cycle. Projects were selected to provide a range of cases at various stages of development (maturity), to help differentiate between the use of human, structural, and relational capital during the project's evolution. Figure 4-1 provides an overview of the range of projects under investigation. Two cases examine projects in their early formative stage, when project teams are trying to craft an attractive business case and identify potential clients for the new product line. Included are examples of projects that are in the early "fuzzy front end" of product development, when knowledge-based assets are important "process enablers" when defining client needs and generating program requirements[68]. Other cases examine intellectual assets during the detailed design phase, when creativity and iterative exploration of design space are important capabilities for the team. Two other cases look at projects that have reached their completion, providing an opportunity to investigate the "cradle-to-grave" evolution of IC assets and their influence on first-article hardware delivery, export restrictions, product support, and client satisfaction. Note that the cases also represent a diversified mix of products for both commercial and military clients.

INCREASING PROJECT MATURITY ↓

| Phase of product development | Case studies | COMMERCIAL | MILITARY |
|---|---|---|---|
| Business acquisition and business case development | **Case Study A:** Commercial derivative of a military aircraft | ✓ | ✓ |
| | **Case Study B:** Conceptual development of an experimental aircraft | ✓ | ✓ |
| Detailed design and development | **Case Study C:** New instrumentation for military aircraft | | ✓ |
| | **Case Study D:** Intelligent design software for aircraft design | ✓ | |
| | **Case Study E:** New avionics for commercial aircraft | ✓ | |
| Product delivery and project completion | **Case Study F:** Lease of military aircraft to a foreign country | | ✓ |
| | **Case Study G:** New line of commercial satellites | ✓ | |

**Figure 4-1 – Scope of product development case studies**

The variety of product development projects lends itself to comparative analysis of the case studies, allowing for pattern matching and explanation building as the projects evolved over

[68] See Wirthlin, J.R., "Best Practices In User Needs/Requirements Generation", MIT Thesis, 2000.

time. The selection of cases therefore provides multiple sources for examining the causal relationships between intellectual capital and the success and failure of product development projects.

These seven case studies represent projects that matched the selection criteria, cover a diverse range of products, and were made available for study by senior management at each corporation. Potential case studies were first identified at preliminary site visits; options were later narrowed down by management, based on internal considerations at each firm. It is important to note one of the practical considerations in case study selection: project choice is restricted to those cases where access to data is granted. The motto that "beggars can't be choosers" always applies to academic research. This is not to criticize the quality of the cases presented here; rather, it highlights that some selection bias may be present in the cases investigated here.

### *4.4. Case study method*

After initial field visits to the project sites, a multiple-source case study methodology was selected for the research. Exploratory discussions with managers and staff members quickly confirmed the difficult nature of performing research on intellectual capital: although all interviewees acknowledged its importance, it was hard to identify which intellectual assets contributed to specific outcomes in product development projects. Although survey data collection was considered as a possible method, it would have been difficult to craft a survey that captures the unique and subtle role of knowledge in different projects, especially given:

- the highly-embedded and synergistic nature of intellectual assets in product development
- the difficulty for interviewees to identify and quantify intangible assets
- the subjective nature of intellectual capital assessments from sample to sample

Clearly, a case study methodology was best suited to explore the complex role of knowledge-based assets, as it allows for the collection of a broad range of data within the context of each individual project.

After preliminary discussions with program managers, site visits were arranged for 2-3 days of data collection for each case study. Site visits consisted of introductions, attendance in team meetings, staff observations, and interviews of project team members. These 49 interviews formed the bulk of the data collection, with a trend towards more interviews with increasing project maturity:

- Case A: 4 interviews
- Case B: 4 interviews
- Case C: 5 interviews
- Case D: 7 interviews
- Case E: 10 interviews
- Case F: 12 interviews
- Case G: 7 interviews

The program manager and chief engineer were sampled in all case studies; other interviewees included executives at the VP level responsible for project oversight, project engineers, and senior members of the design staff with functional responsibility for critical subsystems and components. A protocol for conducting interviews was established, using a list of questions to guide an interview session of approximately 45 minutes to 1 hour in length. Towards the end of each session, opportunities were given for informal, adaptive collection of anecdotes and personal perceptions about each project, with the goal of identifying key drivers and lessons learned that may have been missed during the interview. Although some documentation and archival records were examined to provide background and context for the study, site visits and interviews of project staff were the principal sources of data for each case study.

Interviewees provided important multiple sources of data for each case study, which helped address research concerns about reliability and subjectivity in recalled assertions. The validity of the research method was addressed in the following ways:

- *Construct validity:* Multiple sources of data were used at each site, combined with multiple cases of product development projects. Constructs about the role of intellectual assets were developed and refined based on these multiple observations.
- *Internal validity:* The similarities and variations in the selected case studies allow for pattern matching, investigating rival explanations, and exploring the temporal evolution of projects and their intellectual capital needs as they mature over time.
- *External validity:* Given the selection criteria for these case studies, the results of the research should be generalizable to development projects (aerospace or otherwise) which involve highly complex technical products or services.
- *Reliability:* To promote reliability, multiple interviews were collected at each site using an established protocol for data collection.

Drafts of each case study were also provided to each project manager to assure factual correctness and confirm that proprietary data was not accidentally disclosed. After each site visit, the results from the case study were then analyzed to inductively refine the theories in the intellectual capital conceptual framework; Figure 4-2 provides a good summary of the multiple case study method used in this research[69].

[69] From Yin, R.K., *Case Study Research,* Sage Publications, Thousand Oaks, 1994.

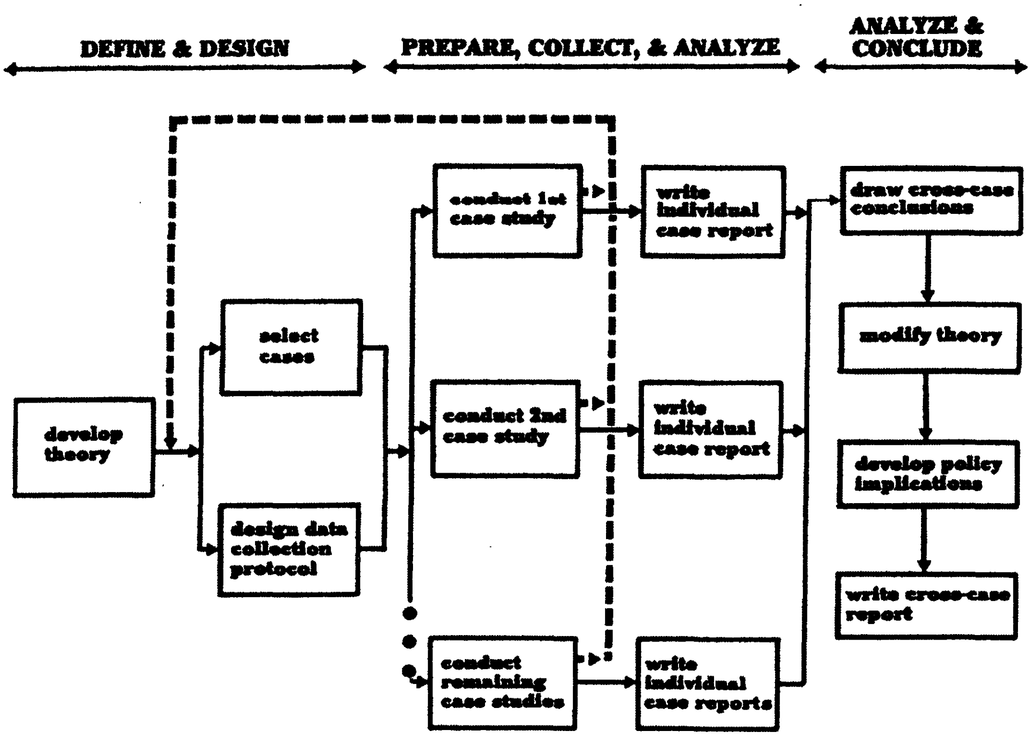


**Figure 4-2 – Multiple case study methodology (from Yin, 1994)**

### *4.5. Linking Data to Theory*

With this research methodology, the case studies should provide the necessary data for validating or disproving the claims made in the intellectual capital framework. The goal of the effort, then, is two-fold:

- Advance the theory of intellectual capital, by developing a valid framework for improved understanding of knowledge-based assets
- Advance the application of intellectual capital, by developing tools that can help managers identify and use knowledge-based assets in their firms

Armed with both theory and data, the research hopes to show how a firm's intellectual capital – its knowledge-based resources and the capabilities that are derived from them – can lead to improved performance and competitive advantages. The details from each case study are presented in the following chapter, followed by an analysis and discussion of the significant findings from the cases.

# 5. Case Studies

## *5.1. Overview of Case Studies*

Seven case studies were performed to explore the role of intellectual capital in product development. As discussed in the last chapter, each case study looked at an aerospace product development project, with visits and interviews of team members at each corporate site. The cases were selected to provide a range of projects – involving business case development, product design, and hardware delivery – to highlight the changing needs for intellectual capital over the course of product development.

This chapter includes the details of each case, and discusses how the intellectual capital of each company – its knowledge-based assets and the capabilities that are derived from them – contributed to the success or failure of the project. Each case also identifies the unique challenges that were faced by the project team, showing not only how intellectual capital needs change during different phases of product development, but also how these needs are both project-specific and firm-specific. To summarize, the following cases are included in this research:

- Case study A looks at the business case development for a commercial derivative of a military aircraft. This case shows how a firm can leverage its relationship with a client (based on a history of strong past performance) to create an innovative business plan.
- Case Study B examines the early conceptual development of an experimental aircraft with possible dual-use applications. The project highlights the crash-course development of new design skills, and the importance of validating design concepts using advanced modeling and hardware demonstrations.
- Case Study C examines a partnership for the design of new instrumentation for military aircraft. The case explores the unique teaming arrangement between the partners, allowing not only the sharing of proprietary data, but blending the strengths of two companies to create customer value.
- Case Study D looks at the development of intelligent software for aircraft design. The case investigates the role of knowledge capture and re-use in engineering product development, and highlights some of the organizational challenges for implementing innovative knowledge management projects in aerospace firms.
- Case Study E explores the organizational processes for implementing a new avionics package in commercial aircraft. The project provides a comprehensive overview of how a firm's knowledge-based resources contribute to strategy development, the formation of partnerships with suppliers, and the alignment of internal stakeholders to integrate the avionics in existing platforms.
- Case Study F documents an effort to develop and lease military aircraft to a foreign country. The case highlights the importance of relational capital in forging unique business arrangements, overcoming regulatory hurdles, and creating winning value propositions for multiple stakeholders.
- Finally, Case Study G looks at the development of a new line of commercial satellites, involving an international partnership to meet project goals. The case explores how a firm's

knowledge-based assets contribute to the collaborative design of complex hardware, and how multiple firms can be managed and incentivized to work towards common goals.

The variety of cases forms the basis for examining how intellectual capital can lead to differentiated performance during the product development phase, and how knowledge-based assets – or the lack thereof – can impact the development of complex products.

### *5.2. Case Study A: Commercial derivative of a military aircraft*

The first two case studies examine the role of intellectual capital in the early stages of product development, when a business case for the project is still being developed. This first study examines an effort to develop a business case for a commercial version of a military aircraft. The firm currently manufactures the aircraft for military clients, with these contracts representing a majority of the firm's business. An internally funded project was initiated to investigate possible business scenarios that would promote sales of a commercial derivative of the aircraft. The project looked at whether any money could be made by using the aircraft to provide services in a niche market that had yet to be developed commercially. Managers and strategic analysts at the firm investigated the market, estimated the revenue for a number of business cases, and sought potential clients who would purchase the aircraft to provide these commercial services. The project also investigated the hardware modifications needed for non-military operation, cost for redesign and production of the new aircraft, and regulatory issues for certification and use in commercial airspace.

As the project is pre-launch and still in development, the case study examines the role of intellectual capital in business case formation and early product development processes. In particular, the study looks at the role that relational capital can play in early product development projects. The unique relationship between the firm and its military client was leveraged to promote an innovative business plan for dual use of the aircraft. This plan incorporated the military client in a joint government-industry purchasing strategy, with shared usage of the aircraft for commercial services and defense needs. A fractional ownership plan would allow for a public-private acquisition strategy, with increased sales of the aircraft for the firm. The case study highlights the enabling role of relational capital in the business case, as well as its importance in developing a market for commercial sales of the aircraft. The study also looks at the human and structural resources needed for business case development, cost and revenue modeling, and inter-divisional knowledge transfer. These assets allowed the firm to identify potential clients, promote the unique capabilities of the aircraft, and establish a foothold for sales of the aircraft in non-military applications.

#### *5.2.1. Project Goals and Implementation*

Seven years earlier, senior management considered expanding the market and developing commercial applications for their military aircraft. For a number of years, the idea did not proceed past the formative stage, as the firm focused its attention on improving operations and correcting problems in their existing contracts. After a rocky period, the firm was able to improve quality, control schedules and costs, and establish a strong track record of delivering aircraft on time and within budget. This turnaround helped to build relational capital with the customer, fostering a sense of mutual trust between contractor and client. With the program stabilized, management was able to turn its attention to developing new business cases for commercialization.

Leveraging the strength of their relationship with their military client, the firm investigated possible teaming arrangements that would promote commercial sales of the product. An important breakthrough occurred with renewed interest from a senior official in the government's military acquisition office. Serving as a project "champion", the official proposed an innovative partnership that would benefit both the firm and the federal government. The idea was to develop a joint military-industry acquisition strategy, with an up-front government investment to secure partial use of the aircraft for the civil reserve air fleet. The concept was fleshed out during meetings between the official and senior management at the firm, and a one-year study was funded to determine the feasibility of the project.

From the point-of-view of the acquisition community, there were a number of potential benefits from a military-industry partnership. Dual use of the aircraft could save several billion dollars in acquisition and life cycle costs, provided that an acceptable sharing arrangement could be reached. Firms could use the aircraft for commercial applications, with part-time military usage in times of need. In essence, the military would get a source of emergency aircraft capability without directly paying for it. Guaranteed orders for more planes would also permit the contractor to operate at lower unit production costs, with additional acquisition savings.

From the contractor's point-of-view, any arrangement that resulted in increased sales of the aircraft was a "win-win". With the potential need for dozens of additional aircraft, the project would add stability to the firm's business outlook, allowing for staff retention and keeping production lines open longer. Increased orders could also create economies of scale with more efficient production, reduced costs, and greater profit awards for the firm. Management therefore agreed to cooperatively develop a business case for the "fractional ownership" plan, and began to assess the market potential and develop commercial interest in the project.

First, the firm enlisted the help of out-of-house resources for market research in this business sector. Having a history of exclusively military sales, the division's managers hired consultants to quantify the current commercial market size and estimate potential demand for the aircraft and its services. Importantly, the consulting staff had prior work experience in the relevant commercial sector. Data were collected to support potential revenue models, and were used to forecast the expected market penetration and identify industries to be targeted for these new services.

Using these models, managers and analysts at the firm began to develop possible business cases for the project. Relying on their extensive manufacturing experience, managers were able to develop complementary cost models for product re-design, fabrication, and support, including costs for the entire aircraft logistics chain. Estimates of costs per mile and hours of usage were also developed for each possible business case. The predictions from these cost models were then coupled with the assumptions about market penetration and revenue estimates from the consultant data. After sifting through the results, analysts at the firm were able to identify a profitable business case scenario with candidate numbers for fleet size, life cycle costs, and a percentage of shared usage between commercial and military applications.

In addition to model creation, in-house resources, and consultant support, the firm needed to develop capabilities for marketing and promoting the product. Relational capital, including a knowledge of potential clients and their value propositions, had to be established, along with a marketing strategy to cater to these clients. To build this capital, managers relied upon staff members with prior experience in the commercial sector, and solicited the help of other divisions with commercial product lines. To make contacts, the firm utilized their colleagues in other divisions to identify potential clients and establish key initial relationships. Staff members also developed a marketing strategy by attending conferences and trade shows, in a quest to identify industries with needs for these new services. These fact-finding missions allowed the staff to talk to potential clients, collect anecdotal data, and explore some possible contractual arrangements -- an effort that one manager described as "getting smarter on the markets".

In addition to client identification, managers used the firm's commercial experience base to develop a business case that catered to the client's value proposition. Staff members and colleagues provided important insights about structuring the business case to appeal to potential commercial clients, including preferred contractual mechanisms, guidelines on the recovery of fixed costs, the inclusion of escape clauses, and an understanding of criteria that would be used to judge the viability of the project. Knowledge was also transferred about overcoming regulatory hurdles for commercial certification of the aircraft. Colleagues at other divisions bridged the culture gap between military and commercial enterprises -- these working relationships led to frequent dialogue and a common language between staff members at multiple locations. One manager at the firm noted that "we're good learners, especially when we draw upon commercial expertise in other divisions." This sector-specific knowledge from colleagues and experienced staff was extremely valuable in promoting the project, understanding the internal metrics of potential clients, and formally identifying client needs and requirements.

Based on these efforts, it became clear that incentives and assurances were needed in the business plan to convince commercial firms to participate in the project. Drawing upon the strong relationship with its military client, the firm cooperatively worked with advocates in the acquisition branch to create an innovative incentive plan that would mitigate the risk for commercial firms. First, the military would commit to awarding multi-year peacetime contracts to the commercial firms that participated in the project. By guaranteeing a minimum usage of the product, the military would provide an established revenue stream, effectively defraying some of the upfront acquisition costs of the aircraft. In addition, the military acquisition agency would guarantee the project by committing to buy back the aircraft if the commercial firms balked from the project. This provided an escape clause for firms if the business failed to develop as predicted. In return, the military would receive guaranteed usage during national emergencies, and peacetime reserve capability without having to buy the aircraft.

On paper, this appeared to be a winning proposition for the military acquisition community. It is noteworthy that the government's willingness to mitigate risk and provide upfront financing for the project was based on the firm's past performance and the strong relational capital between contractor and military client.

In addition to government incentives, the prime contractor also pledged to offer aircraft support services to entice commercial firms to the project. By offering a maintenance contract to service the aircraft at predetermined rates, the contractor hoped to provide a simplified, turnkey solution for supporting the new aircraft. The program manager also pledged to use the firm's extensive resources and industry connections, from aircraft financing to the entire logistics support chain, to provide cradle-to-grave incentives for firms to participate in the project.

#### *5.2.2. Challenges*

In addition to establishing a client base, the project team was challenged by a number of regulatory issues that needed to be resolved before the aircraft could be sold and used commercially. First, the project would need to clear some regulatory hurdles at the federal level. Operational and export restrictions would need to be eased to allow the commercial use of formerly designated military aircraft. Congressional approval would also be needed to give requisite authority to the procurement branch to establish the unique partnership with industry on the project.

In addition, the project team faced a myriad of regulatory challenges before the aircraft could be flown domestically. Although the plane had logged thousands of military flight hours, the contractor faced an entirely different set of flight requirements for obtaining FAA certification. With a background primarily in military certification, the project team needed to develop new skills, capabilities, and relationships with FAA personnel, in order to understand all requirements for commercial use of the aircraft. This effort included clarifying FAA requirements, interpreting policy guidelines, reconciling differences in military and commercial certification procedures, and identifying areas where hardware revisions were necessary. Communication systems needed to be compatible for domestic operation, and some military components would need to be modified, replaced, or removed.

To resolve these issues, engineers developed strong working relationships with their FAA counterparts. Early in the project, the firm decided to fund a feasibility study to resolve certification issues for commercial aircraft use. Again, managers drew upon staff members with industry experience, and supplemented the effort with consultants having prior experience in the FAA. The firm's designated engineering representatives worked with the local FAA office to develop draft certification plans that identified hardware modifications, revisions and exceptions to certification procedures, along with areas to be resolved. The study confirmed that certification was "do-able", and helped to build important relational capital with local FAA representatives early in the process.

Challenges still remain today with the ongoing effort to certify the aircraft. The involvement of both military and civilian stakeholders in the project has resulted in a complicated certification process. One staff member noted that tensions sometimes existed between regional offices, national regulatory agencies, and defense procurement officials over regulatory authority and appropriate policy guidelines. Some of this friction arose from early efforts by some stakeholders to intervene in the certification process. To date, certification remains one of the biggest challenges of the project, with staff members working with different oversight agencies to reconcile differences, forge compromises, and reach consensus on certification issues.

Other challenges identified by managers were more organizational than relational in nature. One team member commented that the firm's organizational culture was well suited to a single product family for a sole military client, but sometimes lacked flexibility for new product development. Previous projects emphasized approaches and corporate processes for continuous improvement of the product line, with a strong track record of corporate success. However, the manager noted that established processes, including those deemed as best practices, may need to be modified when developing novel products or services. Processes that promote change, combined with a flexible workforce that is willing to question established approaches, would be needed to implement changes in the aircraft during the later stages of the product development cycle. Other staff members noted that corporate-wide organizational alignment behind the project would be needed to overcome some of the remaining regulatory challenges, including strong advocacy from other divisions to address pending legislative issues.

#### *5.2.3. Findings*

With the project still in the early phases of business case development, it is too early to conclude whether the firm's human, organizational, and relational resources led to the project's success. The firm has continued to promote the dual-use project and develop relationships with potential commercial clients for the aircraft. The firm recently staged a conference, co-sponsored by its military client, to present their business case to companies and financiers, and to receive valuable feedback about the proposed strategies.

However, some observations can be made about some of the underlying intellectual capital that enabled the progress to date. Clearly, the firm's most important asset was its strong relational capital with its military client, which had been established by meritorious past performance on its contracts. The unusual teaming effort between contractor and principal client would not have occurred if the firm had not built goodwill with its sponsor over a number of years. Each brought important resources to the project that, when combined, created unique capabilities for business development in a niche market. The sponsor's willingness to bear some risk and jointly market the new product was an indicator of the importance of trust and relational capital in the early phases of product development.

Also, the early involvement of a senior executive was crucial to the project's development. All interviewees agreed that having a "champion" in the military acquisition office was a major factor in the successful launch of the development project. Intangible personality factors, including the willingness to network at a senior management level and pursue innovative arrangements with other firms, were important in building critical momentum for the project. Advocacy and continued support of the project also served to keep organizational resources aligned behind the project and a signal to all stakeholders of the high visibility nature of the project.

From the firm's perspective, managers also applied the firm's structural capital towards the new business case development. In-house resources were used to develop cost models using data from past projects, and inter-divisional resources were also tapped to identify potential clients and help formulate a value proposition for the commercial sector. In addition to cost and revenue models, the formulation of a marketing strategy for the business case was also a major portion of the project development effort. This entrée into the commercial sector led the firm to develop new capabilities for promoting business development outside of its core clientele.

In the end, the long-term success of the project will also depend on the continued development of new relational capital. The firm will need to convince clients that the aircraft can provide services in a market with sustainable growth potential. To promote this business case, managers need to continue to nurture relationships and develop interest with commercial clients willing to pioneer a new business niche. Ongoing regulatory issues will also require the firm to foster relational capital with the appropriate oversight agencies. In many ways, the case study confirms the central importance of relational capital in early product development projects that are still in the formative stage.

### *5.3. Case Study B: Conceptual development of an experimental aircraft*

The second study – looking at the conceptual development of an experimental aircraft – also involves formulating a business case and the early stages of product development. The firm undertook two phases of initial studies: first, they explored different concepts for the aircraft and identified needed technologies. The second phase attempted to validate the results of the conceptual study using improved modeling and hardware demonstrations of critical technologies. These initial studies were funded by DARPA as part of an effort to develop next-generation military aircraft. The technology could also have future commercial applications, with project goals chosen to satisfy dual-use requirements.

The project required the firm to develop new skills and cutting-edge tools that fostered innovative design and enabled the exploration of design space, allowing them to perform trade studies that compared different aircraft configurations. To execute on the program, the firm needed to assemble a design team, tackle new learning curves, modify existing tools for specialized analyses, and build internal consensus behind the project – in effect, the firm's existing intellectual assets needed to be marshaled to create the new assets needed for the project. In addition to human and structural capital for product development, the case study emphasizes the importance of establishing strong relational capital in developmental projects, especially the role of stakeholder identification and early involvement to enable project success.

### *5.3.1. Project Goals and Implementation*

Within the firm, the project was pioneered by a team responsible for the development of advanced systems. Drawing upon previous corporate experience, the division responded to a DARPA's request-for-proposals for conceptual development of the novel aircraft. Although the firm had extensive corporate experience in military systems, the proposed aircraft was radically different from previous product designs. The firm lacked experience in one of the critical technology areas, and would likely face stiff competition from other aerospace firms with more relevant background and capabilities.

After evaluating proposals, DARPA chose to award three contracts for conceptual design and research to the firm and two aerospace competitors, from which they would downselect before the next phase of the program. To guide the design process, DARPA staff had established a set of performance targets for the project, including vehicle gross weight, payload, range, and goals for the advanced features of the aircraft. These goals and performance requirements for the project were derived from a review of the relevant literature, and were aggressively chosen to be beyond the state-of-the-art in current systems – a common trait in most DARPA programs. The intent was to foster the development of high-risk, high-payoff technologies by challenging firms to identify breakthrough technologies and integrate them into new product designs.

At the start of the conceptual design effort, the firm's development team assessed its corporate design capabilities and developed a plan to address areas of weakness. Based on the ambitious goals set by the client, the technical managers realized that they needed to boost the firm's modeling skills and identify emerging technologies that would enable them to achieve performance requirements for the project. In particular, some of the greatest technical challenges were in the areas of:

- Airframe shaping and aerodynamic analysis of advanced features
- Advanced subsystems using novel and yet-to-be-developed technologies
- Use of new materials for lightweight structures
- New engine development for efficient propulsion

To respond to these challenges, managers devised a plan to procure the necessary intellectual capital, including:

- Rapid skill development by staff to develop technical competency in new areas
- Working with consultants having expertise in specialized technologies
- Partnering with firms having critical technologies, especially in the area of engine development
- Modifying and adapting existing design tools and software for modeling

- Identifying stakeholders and establishing working relationships, to promote awareness and involvement in the project

To tackle the steep learning curve, the design staff first reviewed all available literature on the fundamental topics and state-of-the-art technologies. Much of the pioneering work in the key areas was performed by NASA and military personnel, some dating back to the mid 1960's. Although published literature and final reports from related programs served as a good starting point, the staff found that many important issues were not documented or adequately addressed. One staff member suggested that previous firms often omitted competitively sensitive "jewels" from their reports to protect proprietary information. The literature also lacked the databases of supporting measurements, which were essential to validate new computational models and analysis tools.

In order to help bridge these gaps, the firm initially brought in consultants or "graybeards" to work with internal staff. The consultants were recognized experts in these fields, and included former NASA and armed forces personnel. In addition to sector-specific knowledge, the consultants were important in providing a sense of direction for the conceptual design, or as one engineer put it, to "know how to approach the problem". With this input, the staff was able to boost its knowledge base and identify some avenues for possible design solutions. This external knowledge complemented the internal knowledge assets of the staff, which had extensive experience with advanced design and development of new military aircraft. The firm further supplemented its knowledge pool by partnering with two key firms. A partnership was formed with an aerospace firm having experience in commercial aircraft design, to promote the dual-use applications of the new aircraft. Importantly, the firm also partnered with a leading engine manufacturer with an already established program for new engine development. A collaborative effort with university researchers in engine development was also funded. Since innovations in engine design were crucial to achieving the DARPA goals for the project, the firm needed strong out-of-house relationships to gain access to enabling technologies for the program.

To design the new aircraft, the firm needed to develop new tools to model aerodynamic effects, new materials, and subcomponents. Some of the existing design tools were easily adapted for the work; for example, finite-element modeling tools for structural analysis were adjusted for new materials and environmental conditions. The project benefited from the firm's investment in in-house tool development – software for laminar flow modeling and computational fluid dynamics were extensively used to model aerodynamic effects of the proposed designs. The novelty of the program, however, meant that some tools required major overhauls and revisions to properly model the physical effects of advanced aerodynamic features. Starting with legacy codes, the firm worked with NASA consultants to modify tools for novel analysis work. Tool modification was an iterative process, with dialogue and frequent input from external consultants and counterparts in partnering firms. The tool developers from the different companies operated as a community of practice, developing an expertise in modeling new effects and assessing the validity of the predictions. Given the pioneering nature of the work, one staff member emphasized the importance of recognizing the regimes where tool use was appropriate, and where tool validity was uncertain. A frequent concern was the lack of experimental data for validating these models; an engineer commented, "We're way beyond the historical databases". The major difficulties, he said, were "knowing how deep is the water", i.e. the tool use was appropriate, and whether the new tools accurately predicted the physical phenomena with high fidelity. The tools, he noted, were unvalidated since these computational analyses were not possible until the recent advent of high speed computing and vast computer memory capabilities.

Project managers proposed a number of methods to address the validation issue. Since there was limited published data in the public domain, the plan for the second phase of the project included data collection from proof-of-concept testing in both the lab and the field. Laboratory tests were proposed on models and critical components, including wind tunnel testing. Significantly, a flight test of a modified aircraft would be used to gather test data, compare, and validate the model predictions. In addition to tool validation, the flight test would serve as a demonstrator for some of the novel technological approaches for the aircraft.

The tools and test data would then support the principal analysis task of the project: a trade study that compared and ranked the different conceptual designs. Each new design was judged using performance criteria for both military and commercial applications. As a baseline, criteria such as cost, aircraft range, speed, weight, and payload (human and cargo) were assessed. Additional criteria for military applications, including effectiveness, operational requirements, stealth, and survivability of the aircraft were assessed for a range of mission profiles. With these criteria established, designers could fine-tune each design to optimize performance for particular operational conditions. Using in-house expertise and consultant support, the firm's designers also developed multidisciplinary optimization routines to search for optimal design solutions that satisfied a wide range of functional requirements. Drawing upon "graybeard" input, the best designs would then be downselected for refinement and more detailed analysis. Judgment would play an important role in the downselection process due to the highly conceptual nature of the work. Since designs were performed for DARPA, as opposed to an armed forces client, it was also difficult to assess whether design choices were well aligned with the needs of the military end user.

Accordingly, stakeholder identification and involvement was highlighted by project managers as an important element to confirm the design choices and enable the overall program success. Although DARPA was the primary client, it was important to consider all possible stakeholders when evaluating the design and considering its:

- Affordability: is the design cost-effective in terms of procurement and life-cycle costs?
- Relevance: does it add capabilities to the end user's fleet, and does it support envisioned missions?
- Significance: is it a major development with new capabilities that justify its cost?

As part of the project, the firm's management formally identified stakeholders and began establishing working relationships to determine the value criteria for each party. Stakeholders included potential end users, procurement organizations, systems integrators and research laboratories in the armed forces, as well as their counterparts at NASA and in the commercial sector. To promote awareness and encourage participation by multiple organizations, management established an oversight council for the project that included senior officials from these stakeholder organizations. Efforts to encourage advocacy of the program were also extended to the Congressional level as well. The ultimate goal of these efforts was to foster end user interest in the program and possibly set the stage for follow-on funding for aircraft EMD. Identifying stakeholders, along with developing relational capital in the early phases of the project, was used by the project manager to improve the chances of long-term success for the program.

### *5.3.2. Challenges*

The major challenges facing the experimental aircraft program were technical, organizational, and relational in nature. Technically, the firm needed to develop design capabilities that implemented emerging technologies in new applications, in areas where they had limited prior experience to draw upon. Although the design team had in-house tools for advanced aircraft development, the lack of data for validating tool modifications was troublesome. Also, when drawing upon legacy projects for insights, some designers expressed frustration that the rationales for previous design choices and system engineering decisions were not documented. A designer commented that previous programs did not have well-documented materials from the conceptual design phase with insights behind architecture decisions. A partial factor for this may have been the pressure to reduce the amount of contractually-required documentation to minimize program costs. As one engineer noted, "many things, especially design rationales, are not documented unless they are customer demanded". During the early design process, the team clambered to understand previous designs and their relevancy to the new project, often drawing upon retained staff and consultants to fill knowledge gaps.

Organizationally, the firm needed to mobilize corporate resources behind the project, which required a certain degree of goal alignment amongst its internal stakeholders. In addition to assembling a design team, project managers needed to work with functional leads, senior management, and the finance function to foster support and develop a viable business case for the project. Given the infancy of the project and the experimental nature of the aircraft, the project team was operating in an environment with ever-changing technology configurations and a high degree of programmatic unknowns. Since developmental programs are by nature more dynamic, and often involve higher levels of both technical and programmatic risk, the project manager was faced with the difficult task of building consensus in a risk-adverse corporate environment. This required willingness by functional leads to support the riskier design work, and from a fiscal viewpoint, a willingness to apply different costing standards to the project.

With the potential return-on-investment being years away, the manager also strove to promote corporate support with less emphasis on short-term profitability. Tactics such as smaller management reserves, reduced burdening from indirect costs, and a willingness to "flex the corporate rules" during budgeting sessions were employed when developing the business plan, with the goal of maximizing value delivery within the client's cost constraints. To accomplish this, the project manager needed to have strong interpersonal skills to promote consensus building. The project manager stressed the importance of meeting individually with key internal stakeholders to get "community buy-in" for the project. Often, the ability to persuade relied on an established foundation of trust, based on past experiences, interactions, and the manager's track record of bringing money into the company. As individuals committed to backing the project, important signals were sent to other stakeholders in the organization that the project was legitimate, viable, and worthy of resource allocation despite the additional risk.

Finally, project management undertook the difficult challenge of promoting awareness and developing program advocates beyond the DARPA client. Realizing the importance of strong relational capital for the program's long-term viability (i.e. continued funding beyond design and limited prototyping), project managers sought to involve external stakeholders early in the process. Methods such as the establishment of the oversight council and informal involvement in design reviews were used to promote this awareness. Understanding the needs and values of these external stakeholders was an additional challenge for these managers. Although DARPA was the short-term client, the long-term success of the project also hinged on whether the product satisfied the needs of the eventual end-user community. Informal discussions with stakeholders were used to identify the potential value of the project for commercial and military applications. Often, this discovery process was handicapped by near-sightedness: stakeholders could clearly identify today's operational needs, but were uncertain about long-term needs and strategic acquisitions. The project manager commented that, without a "pull" from the end-user community, it was difficult to garner support from the development and acquisition functions in the various stakeholder organizations.

### *5.3.3. Findings*

Since this case is in the preliminary stages of product development, it is too early to assess how the firm's intellectual assets led to improved performance. However, the case study does illustrate how managers crafted a strategy that focused on the development of intellectual capital, and highlights some of the potential benefits from this approach. From the beginning, project management emphasized an approach to discriminate the firm as a leading expert in modeling and design using novel technologies. The firm embarked on developing its human capital to improve its design capabilities. In order to leverage its knowledge base, the firm modified heritage tools and launched a focused effort to develop cutting-edge simulation capabilities in advanced features. To assist them in this effort, the firm brought in consultants with the required expertise in technologies, modeling methods, and multidisciplinary optimization for its trade studies. This helped to identify areas where novel technologies could be used, and led to strategic partnerships with firms having unique, enabling capabilities. Internally, project managers also used a wide range of personal approaches to align stakeholders and allocate resources to the project.

The firm also committed to developing an early demonstrator aircraft to collect data and perform an in-flight validation of their technological approach. The inclusion of a flying demonstrator in the project strategy was significant as a means to reduce risk and send important signals to all stakeholders. In addition to validating the technology, the embodiment of design concepts in hardware – and the ability to tout that "we've built it" – could serve a psychological role in signaling the maturity of the project, promoting awareness, and indicating the emergence of the firm in this arena. Technical issues aside, the case study hints at the importance of tools, capabilities, and prototypes as a means to develop stakeholder awareness and support.

Finally, management was engaged in a concerted effort to identify stakeholders and their underlying value propositions. To promote its long-term utility, managers made sure that the project was directed towards an end product that could deliver affordability, relevance, and significance to multiple stakeholders. Using communication and networking skills, the project manager reached out to include potential downstream clients in the process, orchestrating an oversight council with representatives from key organizations. Multiple stakeholder involvement could also serve to build credibility and legitimacy for the project, and lay the groundwork for additional funding. In summary, the project required many intellectual assets beyond the conceptual development of an experimental aircraft. The case study illustrates how projects that are still in their infancy have unique intellectual capital requirements, given the large degree of technical unknowns, the challenge of building support for new projects, and the need to secure long-term funding.

### *5.4. Case Study C: New instrumentation for military aircraft*

This case study looks at a cooperative design effort to develop new instrumentation for defense applications. In the past, the prime contractor had designed and delivered a version of the system for use in military aircraft. The new contract was to develop a revised instrument to replace the aging hardware, upgrade its capabilities, and make the technology more scalable to other platforms. Given its past experience, the firm already had an established base of human capital, tools, procedures, and validated data to apply towards the new product design.

To extend this knowledge base, the prime contractor teamed with one of its principal competitors to provide major subsystems and integrate new capabilities into the product. The unique teaming arrangement was formed to take advantage of each firm's core competencies, and included provisions for workshare distribution and the protection of proprietary data. This cooperative design approach was a departure from previous corporate projects, and represented a radically different way of doing business for the firm. This change was driven by two rationales: first, the revised system, by merging the technical strengths of the two companies, would provide enhanced capabilities and deliver greater value to the client. In addition, a modular instrument could be used in a variety of military systems, including applications in different branches of the armed forces. The combination of strong client "pull" and increased market potential led the firm to adopt a partnered approach to the project – and created a "win-win" solution for both firms and client.

The project required the firm to build relational capital, create new resources to enable and sustain a collaborative design effort, and align internal and external resources towards delivering value to the client. This included formal agreements to structure the work, create mechanisms for knowledge sharing while protecting proprietary data, and establish incentives for cooperation between the firms. These arrangements also included provisions for establishing a long-term strategic partnership between the firms on future work in this arena. The case study emphasizes the central role of relational capital in the project, and the importance of developing lasting relational capital beyond the life of the project.

### *5.4.1. Project Goals and Implementation*

Previously, the prime contractor had designed and delivered similar hardware as part of a large military contract, with most of the work being performed by a division on the other side of the country. As a whole, the firm was recognized as having a strong core competency in developing this type of instrumentation, both in its design capabilities as well as its ability to manage projects, integrate hardware, and execute the program on time. Previous instruments had been well received, and their use led to an established track record of performance in the field.

The new project evolved from the need to replace some of these aging instruments. Originally, the firm had been under contract to develop an upgraded variant of the operational system. With the basic technology already proven, the client decided instead to restructure the program, with the goal of gaining additional capabilities in the instruments. Rather than simply upgrading the deployed systems, the client pushed for a new design that would allow the product to be more widely implemented in various military platforms. Instead of a "point design", the proposed instrument would better suit the client's needs by:

- Emphasizing a modular design approach, which allowed the hardware to be scaled to different aircraft and different applications.
- Incorporate new capabilities that enhanced the instrument's functionality and delivered additional value to the end user.

To provide these additional capabilities, the client urged the prime contractor to team with another firm having complementary strengths in the area. After extensive three-way negotiations, the client and the two firms were able to outline a plan for structuring the partnership, establishing draft specifications, and dividing the labor between the teams. The restructured project would now allow the client to merge the technologies of the two firms – as one manager put it, the teaming "brought the best of both worlds together" in one system.

From the client's perspective, a modular system emphasizing commonality between components on different aircraft would also lead to significant long-term cost savings. Short-term increases in non-recurring design costs, especially considering the need for coordination between two firms, could be offset by long-term decreases in recurring hardware and life-cycle costs. Combined with the added functionality, the client had strongly advocated the partnered approach to the project.

From the prime contractor's perspective, teaming on the project was not the obvious approach. Given the intense competition between firms for previous contracts, the two companies would make for unlikely partners. In the end, however, the two firms agreed to team on the project for a number of reasons. First and foremost, the firms were responding to the strong client "pull" for merging their technological approaches together to enhance and deliver client value. In some respects, the project was a "forced marriage" where partnering was viewed as the critical, enabling factor to winning the contract – the firms were incentivized to team together to create a "win-win" situation rather than a "lose-lose" one. Additionally, the proposed changes to the instrument would also create a product with greater market potential. With modularity, the instrument would be adopted on multiple systems, including the potential for use on other emerging platforms. The prospects for foreign military sales and novel military applications were also considered in the strategic decision making process. Combined with the obsolescence of deployed systems and the need for incremental upgrades, the senior management at both firms decided that a strong business case existed for partnering on the project and sharing the larger potential market.

To successfully combine their organizational capabilities, the prime contractor and its partner first needed to agree on the terms for work distribution, chain of command, and protection of corporate trade secrets. As part of the contract, a teaming agreement was drafted that formalized this newly forged relational capital. The agreement explicitly spelled out the terms for the sharing of responsibility, authority, and accountability between the two firms, including details on the division of labor for the project and procedures for data sharing. The contract also defined mechanisms for the resolution of conflicts and the protection of proprietary data.

In addition to defining each firm's operational responsibilities, the teaming agreement also had financial significance. During negotiation, the client advocated that a portion of the contract award fee be tied to the degree of cooperation and sharing between the firms, as determined by the client on an annual basis. After inclusion in the contract, the award fee became a tangible, financial incentive for the two firms to collaborate and combine their technologies – and deliver value to the client. By cross-pollinating the two technologies, client value would also be created in the process as well as the end product. Therefore, the two firms not only needed to cooperate for operational reasons, but also needed to maintain an open, collaborative environment (or at least the perception of one) for receiving the award fees. In terms of intellectual capital, the teaming agreement served as a mechanism for establishing relational capital, incentivizing each partner, and aligning corporate interests with client value.

The implications of the teaming agreement also extended beyond the current project. In the long term, the agreement was formulated to allow for teaming on follow-on contracts and future military procurements of related systems. In this sense, the agreement was a strategic decision by the firms to promote the sharing of follow-on jobs and future work in this area. Rather than returning to a competitive environment, the firms hoped that the agreement would serve as a basis for a long-term partnership – and as a means to create lasting relational capital.

With the partnership established, the prime contractor proceeded to assemble the necessary intellectual assets to execute the project. Needing systems engineers and specialists with experience from the previous instruments, the firm transferred three key staff members from the division responsible for a major subsystem. The project team not only drew upon their previous experience in designing and fabricating instruments, but also utilized their ability to span the boundary between the division and the parent organization. Despite differences in management styles between the two divisions, the transferred staff commented that they were able to maintain relationships and facilitate in communication and knowledge transfer between organizations. Importantly, since the staff provided continuity to the knowledge gained from previous programs, the firm was able to leverage the heritage of their human capital on the new application.

The initial project phase concentrated on developing a conceptual design for the revised system and a plan for implementation. The design work emphasized an open architecture for the system, with trade studies to examine the performance of various designs on different platforms. To perform these studies, the firm drew upon established, well-understood models from previous instruments – models that had been validated by extensive testing and data from usage in the field. The novel aspect of the design work was extending the firm's previous designs and optimizing for modularity and commonality, so that the new instrument could be adapted and scaled to a range of generalized applications.

In addition to human capital and corporate experience in the design process, the prime contractor also employed its management experience to coordinate efforts with its partner and suppliers. The firm drew upon established planning processes and procedures to manage the complexity of a multi-team project. As the prime, the firm also assumed responsibility for systems engineering tasks, including the integration of the various technologies into the instrument. These roles required a strong relational capital base to manage geographically and culturally diverse organizations, as well as tools to coordinate efforts and promote knowledge sharing between partners and product teams. This relational capital was critical in leading a multiple-firm operation that one manager described as a "virtual organization". The prime contractor needed to manage and coordinate with its partner, with corporate divisions that were scattered across the country, and with a nationally distributed supply chain. Since the instrument would be incorporated into a number of aerospace systems, the project team also needed to interface with different platform developers. Given this spread of external stakeholders, the prime contractor's ability to perform management and oversight from a distance was an essential capability for program execution.

To enable distributed management, the project team developed tools for exchanging design information and checking IPT status on a daily basis. A major initial task was to develop an on-line IT management system for collaborative work and project management. A management framework with a web interface was established to allow partners, suppliers, and the client to exchange files and check project status. This system included document management, requirements tracking, interface control, and project management tools with formalized performance metrics. Importantly, substantial security efforts were made to prevent outside access to proprietary data in the system. Externally, the IT system was quickly adopted by the client and external IPTs as a means to check program status and coordinate efforts. Since it was easier for in-house staff to resort to less formalized means of data transfer, one engineer noted that, internally, engineers were less inclined to use the system. To promote adoption, project managers preached the importance of using the web-based management system, especially given the collaborative incentives that were tied to the contract award fee.

In addition to the IT management system, more conventional tools were also employed to promote knowledge transfer and project control. A steady stream of phone conferences and emails were also used to supplement the IT management system. To foster knowledge sharing between the partners, a regular schedule of joint meetings was established at alternating locations. IPTs met on a monthly basis, with attendance by counterparts in each organization. The project plan also called for joint participation and attendance at all design reviews. Staff co-location was not emphasized in the project plan – one engineer noted that, "fortunately, much of the work is compartmentalized" and allowed for independent design efforts by the various teams.

Given their competitive history, two issues were extremely important to establishing a successful relationship between the partners: the division of labor between the firms and the protection of corporate proprietary data. Before the start of the project, the prime contractor negotiated with its partner to determine how to divide up tasks and responsibilities. Management at both firms agreed that the workshare would be evenly distributed between the firms at the start of the contract, with the key subsystems assigned outside of the prime contractor's organization – one manager noted that it was highly unusual to have an external partner manage the principal IPT for the project. This workshare was consistent with the firm's management philosophy, which emphasized a decentralized teaming structure that empowered each organization to perform its tasks. A project manager commented that "responsibility, authority, and accountability were pushed down to the IPTs" as means to empower each group and promote a sense of ownership. In this sense, staff empowerment served as a means to align internal and external stakeholders, thereby enhancing both structural and relational capital. The agreement between the firms also incorporated flexibility in the division of labor, so that the lead roles could change as the system was developed for other platforms or different applications.

When deciding on the division of labor between the partners, it was also necessary that senior management resolve how to protect of proprietary data. For competitively sensitive tasks, managers first needed to agree on which firm was best suited to perform the work. These decisions required an understanding of which partner had the best resources for the task, including details about proprietary technologies for subsystems. In a highly collaborative environment, managers faced the dilemma of balancing their "need to know" with protecting trade secrets. To make these decisions, the teaming agreement in the contract included a unique provision where a limited number of senior managers from each firm were allowed to review proprietary materials. These managers would collaboratively determine how to best apply their combined resources to the project, without disclosing proprietary information to the rest of the team. This arrangement served as a mechanism to protect proprietary data while still allowing each firm to apply their unique capabilities to the project.

### *5.4.2. Challenges*

Since both of the partnering firms had past experience in building related instrumentation, the greatest challenges of the project were not technical, but relational. Managers at both companies needed to foster cooperation between teams and develop tools for boundary spanning between the firms. Joint meetings and shared data management systems were only a first step towards establishing a collaborative environment for the project. Team members needed to make a "conscious effort to play well together", according to one project manager. The coupling of the contract award fee to the degree of cooperation between the firms served as a tangible incentive for collaboration – but as one team leader pointed out, engineers still needed to "walk the talk" and work together to create an collegial environment for communication between the firms.

In addition to having a willingness to collaborate, team members needed to overcome differences in corporate processes and corporate culture. Substantial differences existed in the way each firm approached the design process for similar instruments. A systems engineer noted that the firms "don't speak the same language", with teams using different terminology when trying to characterize a major subsystem. Counterparts in each organization also used different CAD tools, further complicating the process of data exchange and knowledge transfer. Despite the shared data system, one manager expected that software differences for requirements and specifications management would lead to difficulties later in the project. The web-based IT management system was expected to address some of these problems, but a need for people and tools for boundary spanning between the partners still existed. Although managers were aware of these challenges, they did not identify other formal mechanisms for promoting communication and knowledge transformation across these corporate boundaries.

Finally, the project manager acknowledged the challenge of leading a large project with distributed responsibility. By employing a decentralized management approach, some crosscutting issues became difficult to coordinate and manage. The project manager admitted that "the lines of authority are not always clear" in some technical areas, and could possibly result in confusion about responsibility and accountability. Issues in these gray areas would be resolved by the program manager and chief engineer, with input from the affected teams. In general, the management philosophy emphasized seeking consensus on unresolved issues, with the goal of achieving "buy-in" from all the involved stakeholders.

### *5.4.3. Findings*

To date, the partners have developed a concept for the baseline design the instrument, which incorporates the advanced technologies from both firms. Program reviews have been held of the system requirements and key subcomponent requirements, with the first major design review slated for later this year. Although the project is still in the early stages of the product development cycle, the design effort is on-track – and the program has undergone major reviews, indicating the strong health of the project.

To date, some preliminary findings can be drawn from the case study about the "mix" of intellectual capital that were brought to bear on the project. Clearly, the prime contractor and its partner had an established base of experienced staff and relevant knowledge captured from past projects. Given this human capital and structural capital, the firms seemed well positioned to execute the product development tasks of this contract.

It was the relational aspects of the project, however, that necessitated the development of new resources and capabilities by the prime contractor. First, managers needed to be willing to accede to a client who championed a different way of doing business – and re-align corporate resources and key relationship to match the client's definition of value. Realizing that mutual benefits that could be gained by both firms and client, the firm extended itself to incorporate "not-designed-here" hardware and an external partner into the program. Working together, they developed a number of mechanisms to build relational capital and deliver value to the client. First, the contract was drafted to incentivize the firms to collaborate and cross-pollinate their technologies. In addition to the award incentive, the contractual arrangements were specifically structured to promote communication and coordination between the firms. The partnering agreement formalized and defined the ground rules for workload distribution, proprietary data, and knowledge sharing on the instrumentation project. Importantly, the project also served as a catalyst to establish a long-term strategic partnering between the firms, thereby developing lasting relational capital beyond the life of the project.

Finally, the prime contractor also made some needed investments in tools to bolster this relational capital. The distributed nature of the workforce almost necessitated the development of web-based tools for collaboration, concurrent design, and client involvement. Tools, however, are necessary but not sufficient for effective knowledge transfer – people are still needed to transform this knowledge to create value for the client and the firm. The challenge remains for counterparts at each firm to effectively use these tools, transfer knowledge, and span boundaries as they continue with the product development process.

### *5.5. Case Study D: Intelligent design software for aircraft design*

Intelligent Design Software (IDS) is an ongoing program for capturing and employing detailed design knowledge at an aircraft manufacturer. To date, the program has been deployed in various functional groups – including fuselage, wing design, tooling, weights, and systems engineering -- that support the design of product derivatives for the firm. In conjunction with CAD software, databases, and AI languages, the IDS group developed customized software routines for designing aircraft components. These routines allowed each function to automate repetitive tasks, reduce variability in the designed components, and created a systematic approach for design and documentation. In this sense, the case study is a good example of lean implementation during the design phase of a program.

The initial application of intelligent design software at the firm was in a design team working on fuselage structural components for an aircraft derivative. The team was faced with the design of numerous parts that make up the fuselage; these included frames, aircraft skins, stringers, shear ties, clips, and other small components that are required in large volume. Although many parts shared common features, the complex requirements on each part (in terms of stress, size, and fit) usually led to multiple design iterations and large part counts for uniquely customized components. By developing an intelligent tool for engineers, the IDS group hoped to automate the process, promote commonality and part re-use, and capture the underlying "rules" that governed the design process.

The implications of this case study, however, extend beyond the development of computer-based design tools for engineering. Many of the "lessons learned" from this study have a bearing on topics such as knowledge capture, knowledge re-use, and the development of structural capital for the firm. The software not only serves as a timesaving design tool, but as a means to codify some elements of human capital and capture underlying rationales for design choices – creating structural capital that persisted beyond the life of the program. The case study looks at the attempt to expand their program to other functions, other platforms, and other phases of the product development cycle. Their struggles illustrate some of the organizational barriers to knowledge capture and highlight important methods for overcoming these obstacles.

### *5.5.1. Project Goals and Implementation*

The Intelligent Design Software effort could be viewed as an internal product development project, with the fuselage structural group as its first client. Working on a derivative of an existing aircraft product line, the IDS staff consisted of 12 people as part of the larger 450 person integrated product team (IPT). Engineers with a minimum of 5 years of experience were recruited and drawn from the functional groups that supported the IPT. It is notable that programmers from the corporate Information Technology (IT) department were not initially recruited for the IDS development effort. The interviewees cited multiple reasons for using engineers for IDS development instead of programmers:

- Since the task involved a mix of engineering and software knowledge, it was necessary to develop staff with interdisciplinary skill sets. As one manager put it, it was "easier to train engineers to do IS [information systems] than it is to train IS staff to do engineering."
- A deep understanding of the functional discipline was needed to write intelligent routines for engineering and design. Accordingly, IDS managers tried to recruit the "domain experts" in each group to develop the design rules for each task.
- A team leader emphasized the importance that the application developers come from the end-user community. For the program to be respected and the product treated as credible, it was necessary to "pull" engineers from each of the functional groups.

After the engineers were brought on board, they were trained in programming techniques and IDS methods during 4 weeks of fulltime instruction. The IDS team also held half-day workshops periodically to provide additional training, meet as a group, and share experiences from their work.

The project also benefited from the support of the firm's IT department. Although not recruited as developers, the IT staff acted as coaches and mentors to the engineers for code development. They also created and maintained the infrastructure that supported the project's development efforts. According to one manager, collaboration and support from IT was absolutely critical, since interfaces and translations between CAD environments and the programming environment needed to remain stable. Rather than being territorial, the IT department adopted an enabling role for engineers doing programming work, serving as an important corporate resource for the developing capabilities and getting the project rolling.

At the beginning of the program, IDS managers defined objectives and developed an implementation plan for the effort. Working with representatives from the functional groups and IPTs, goals would be defined for the IDS project, including desired features and benefits from the software. The objective was to develop a software tool that would:

- Automate repetitive design processes
- Reduce variability in component designs
- Capture detailed engineering knowledge and promote knowledge re-use

In addition, their goal was to smoothly integrate this tool with the existing CAD software and design processes. For successful implementation, the managers felt that the IDS software needed to be more than just another tool, but an integral component in the design process.

Automation of tasks was an important first step in creating a useful product for the engineering staff. Since the product development process required an iterative exchange of information between design and analysis tools, the IDS software included features for automating the time-consuming tasks of data translation for import and export. The IDS routines generated files needed by the different analysis software packages; conceptually, these files could be thought of as "multiple representations" of the current state of the design. This translation feature of the IDS software was straightforward, since analysis packages and their data formats were already well established. To support the evaluation process, software was also created for generating data files and reports. This resulted in more uniform data structures and less variability in reporting, allowing for easier assessments of design changes.

Another routine in the IDS application helped generate fabrication drawings and machine codes for CNC manufacturing of parts. In a situation where different suppliers were slated to provide parts, customized versions of the code were created to tailor the output to each supplier's processes and drawing call-outs preferences. By automating the analysis and data export processes, the IDS software allowed for faster iterations during product development, with the benefit of reduced risk and uncertainty in the EMD phase of the program.

Beyond simple data translation, the IDS software automated tasks by developing "rules" which governed the design of specific parts. Using their engineering experience as a guide, the IDS staff developed stand-alone routines that generated commands for their programmable 3-D CAD packages. These commands served as a "macro" that governed the sizing and shaping of specific features (such as bevels, tapering, edge margins, etc.) on each part. In addition, the routines drove the design of parts towards commonality – the software would try to optimize the design of common parts by finding a set of solutions that maximized common features and minimized the total part count. These "rule sets" were developed for specific part types, and involved different characteristics of each component:

- Constraints on part sizing, including assigning the necessary structural thickness
- Rules on common features such as holes, bevels, and fasteners
- Orientation and positioning rules for repeated components
- Producibility rules, with input from manufacturing engineers and machining shops, about machining capabilities and cost-effective design

These rules were used to force the CAD system to automatically assign default characteristics for a part, thereby promoting common features, reducing the part count, and incorporating past experiences into the design of each part.

As a means of developing structural capital, the IDS tools were perhaps most important in capturing tacit design knowledge. The software (including comment lines in the code) served as an embodiment of design knowledge that often disappeared as engineers were transferred or left the company. To support the software, user's manuals and reports were created for each application that documented design rationales for the software and criteria for decision-making. In the past, comparable tacit knowledge was captured only in corporate design manuals – a process that had been sporadically used and infrequently updated since the early 1970s. Although the manuals were still available, they were irregularly maintained and accessible only in paper form with no search capability. The reports on the IDS applications documented design rules, but just as importantly documented the underlying design rationales and assumptions behind engineering choices. In this regard, IDS software and documentation served as a valuable tool for knowledge capture and represented one of the best practices of the program.

The engineers of the program also felt that IDS could serve as a unifying data structure for managing the project information systems. Before IDS, the 3-D CAD system served as the reference IT platform and the repository of design data. However, managers estimated that CAD files hold only about 25%-30% of the information needed to fully define all aircraft parts. Since the IDS system served as the data manager, translator, and interface between the CAD and other analysis software, a fully developed IDS platform could serve as the central repository of all project design information. In summary, the multifaceted benefits of the IDS system – reduced variability, process automation, and knowledge re-use – could shorten design time, reduce rework and waste, and allow the engineering staff to concentrate more on "creative design time" and less on mundane tasks.

### *5.5.2. Challenges*

Although a host of benefits were reaped from the pilot program, the IDS staff found it difficult to establish the program and achieve widespread adoption of its tools. This difficulty was partially a consequence of the lack of indirect or overhead funding to support project development and implementation. To make the program more attractive, the management of the IDS group initially proposed an aggressive approach in order to cover its startup costs: a "pay as you go" funding plan that was drawn from cost savings. Rather than soliciting startup funding through regular corporate channels, the IDS group would cover its costs from the expected savings in program manloading. At the start of the effort, the team would sit down with the functional group lead and make a mutual assessment of the expected benefits of the IDS project, including an estimate of the head count reduction from program implementation. A portion of the expected savings would then be used to fund the program, with a commitment from the IDS team to achieve and perform as agreed upon. Without requiring additional budget for the program, the IDS managers felt that they were aggressively minimizing the up-front risk, and that this would encourage participation from IPT managers.

This approach, however, did not always lead to adoption and establishment of the program as planned. Despite no upfront costs, risk-adverse managers were not inclined to take a chance on an unfamiliar and unproven program that could disrupt team performance. The downside of the program – including the upfront headcount reduction, the potential for re-work, and possible schedule slippage – was too great a risk for many functional leads to shoulder. As a result, thorough implementation of the program has been limited to the design of fuselage and wing box components on some of the platform derivatives. With no IRAD dollars or other sources of funding, the IDS program managers face an uphill financial battle for establishing the program in other functional groups.

In general, resistance to IDS adoption fell in a few broad categories:

- *Confusion about IDS.* IPT managers having no experience with the IDS pilot effort were less likely to understand the processes and benefits of the program. Some managers perceived IDS to be "just another IT tool". As a non-traditional IT tool, IDS then had to compete for funding against traditional IT tools (including CAD systems, databases, and intranets) that were well established. A possible solution, as suggested by one IDS project leader, was to get more senior managers with IDS experience as IPT leaders, or to rotate managers through the IDS group as part of their career development.
- *Uncertainty about the value-added from IDS.* As a novel and unproven program, functional managers questioned whether the benefits outweighed the time and cost of the IDS program. In addition to developing tools, engineering staff would need to learn how to use them effectively. Without prior experience with IDS, many managers were skeptical about the predicted benefits.
- *Organizational culture.* Some obstacles could be attributed to the organization's reluctance to change. Since the IDS program was initially developed in the functional group for airframe structures, there was reluctance from other functions to adopt a tool that was "not invented here." Another tendency of organizational culture was "contractor mentality" of the engineering staff, where "more manhours are better", according to one manager. Since the IDS project required a reduction in the headcount to fund its implementation, the manager pointed out that "it's hard to convince people to promise more than they've delivered in the past with a reduced level of staffing."
- *Organizational CAD-centric bias.* One of the principles of the IDS effort was that engineering processes should drive tool development, and not the other way around. However, one manager asserted that, due to the rapid advance of computing technology,

engineering disciplines have been slow to take ownership of the processes that now rule their environment. In addition, IT organizations have become tightly aligned with major CAD vendors – a mutually beneficial arrangement that controls the development of CAD tools. According to this manager, IT organizations are guaranteed large budgets in order to sustain essential, complicated CAD systems, while CAD vendors are guaranteed a captive business partners by keeping CAD systems large and complicated. The result is an inflexible relationship that does not cater to the engineering end-user, and ultimately impedes the development of new tools for engineering processes.

- *Threat to engineering culture.* Also, the IDS effort emphasized standardization, codifying those best practices that met requirements, minimized cost, and added value to a design. Much of traditional engineering design, however, includes a degree of artistic license, allowing engineers to creatively develop designs based on individual interpretations of the task.
- *Lack of grass roots support.* Most importantly, some engineers viewed the IDS effort as a challenge to their jobs and a means to eliminate staff. The IDS tool could obsolete certain skill sets for repetitive tasks, and would threaten engineers who were not inclined to adapt and develop new skills.

By funding the IDS projects through manpower reductions, the program unwittingly undermined some support by end users – the design engineers at the grass roots level. Although IDS managers touted benefits to the workforce such as reduced repetitive tasks and more creative design time, IPT leaders saw IDS as a means to lower headcounts. Given management's emphasis on smaller headcounts, the engineering staff clearly sensed that these pilot programs were a threat to job security and resisted implementation at each step. If this sounds familiar, it is because it is a common story: dilemmas of this nature frequently arise when an improvement process or lean implementation is viewed as an attempt to downsize the workforce. The misunderstanding often hinges on whether human capital is perceived as a cost factor or as a source of innovation and competitive advantage.

Long-term adoption was also difficult in groups that initially embraced the pilot programs. Some engineers in these groups responded negatively to IDS, attempting to "stiff arm" and delay IDS implementation, according to one manager. To undermine the credibility of the tool, end users would find fault with the product and the resulting IDS output. Some criticisms of the product were that it would "never be good enough", did not generate the correct solution, or created unvalidated designs that required re-work. IDS developers responded by "raising the bar" and striving for higher quality in the IDS product. IDS managers realized that a partial solution was not particularly useful or politically helpful, and demanded a high degree of fidelity and level of performance from the software tools. These requirements -- full functionality and thorough testing using multiple scenarios – meant longer development times, and the IDS team was reluctant to release the tool until it was nearly complete and thoroughly validated.

When asked about critical factors for early promotion of the project, the IDS team leader identified "effective implementation" as a key factor to early adoption. In hindsight, sound and thorough implementation may have been a necessary, but not sufficient condition for project success. Without strong management support, the team leader realized the importance of internal marketing to establish the program and build support for the effort. With most of IDS staff drawn from engineering, he noted, "we've suffered from low presentation skills, which is important to secure funding for these projects." In addition to greater managerial and financial support, other suggested changes included the use of clearer metrics to judge IDS performance, and a streamlined organizational structure with IDS as an integral part of all integrated project teams.

### *5.5.3. Findings*

Despite efforts to propagate the intelligent design software program, the greatest degree of adoption occurred in the initial teams working on airframe structural components. In these projects, IDS-produced data was used by 30% of engineers on the program, resulting in greater productivity in component design. The airframe team leader estimated that IDS processes were utilized to design the majority of parts, and resulted in a 60-70% reduction of part numbers in the bill of materials.

Although the pilot programs had achieved only a modest degree of penetration to date, the IDS staff were still upbeat about the long-term potential of the program. In particular, the IDS team leader believed that support for the programs would increase as IDS capabilities improved with time. Intelligent design software was promoted by management as a true "kaizen" process, with continual improvements in quality and cycle times. With preserved IDS support of tool development, the design rules would gradually become refined or, as one engineer put it, "honed" by iterative improvements to the code. Given early adoption and continued support, a project manager estimated that IDS processes could lead to a 75% reduction in cycle time, variability, and cost in design processes for new aircraft. In terms of manloading, one manager estimated that staffing could be reduced by 5 people for each IDS staff devoted to a program.

Clearly, intelligent design software does have the potential to reap cost savings, especially for highly repetitive design tasks. However, one of the principal lessons learned from the case study is the critical need to achieve goal congruence and alignment amongst internal stakeholders. The IDS projects were hindered by failing to align the goals of IPT staff, functional groups, and management. In effect, strong components of intellectual capital can be undermined or underutilized if there are weaknesses in other critical areas. Intelligent design software could provide best-practice capabilities for capturing knowledge and creating long-lasting structural capital for a firm. It has the potential to be a powerful force in the quest for "better, faster, and cheaper" performance; it can develop better design tools, automate processes, enable rapid design iterations, and reduce manpower requirements. Importantly, it leverages the strength of the firm's human capital inputs – domain experts with interdisciplinary skills – to create a tool that captures tacit design knowledge and the rationales behind design choices. However, it can also be subverted by a lack of support from management as well as resistance from the grass roots level. Organizational culture, uncertainty combined with reluctance in adopting novel processes, and the atypical funding mechanism all served to temper management support and penetration of the IDS pilot programs.

To avoid these pitfalls, project management could have taken a number of steps to achieve greater alignment and support from internal stakeholders. Some steps to achieve internal alignment – being able to articulate the value proposition, communicate it throughout the organization, provide incentives, and empower the workforce – are discussed in the analysis chapter of this work. Although the IDS pilot program was inserted into various IPTs, the competing interests between IDS staff, functional groups, and management were often never resolved. With resistance from below and reluctance from above, the IDS program has yet to build the support it needs to flourish.

The IDS pilot program is still a "work in progress" -- and in the future, IDS has the potential for other benefits that exceed its current scope. To date, intelligent design software has been customized and developed specifically for each functional group in the pilot programs, with limited sharing between functions or programs. IDS offers the potential, however, for knowledge sharing between all aspects of an organization. In theory, a greater sharing of detailed knowledge about features and lessons learned could lead to a generalized set of rules that promotes commonality across teams and platforms. It could also serve as a means for greater dialogue and knowledge transfer between designers and the shop floor; engineers lamented that current designs are simply "thrown over the wall, and manufacturing issues die on the shop floor". IDS would serve as a tool for formalizing shop floor experiences that are often uncaptured. Extending the concept further, IDS could someday be applied to all external downstream processes, serving as a portal and repository for supplier processes, supplier-specific design rules, manufacturing issues, and product lifecycle data. In theory, the robust potential of IDS could be generalized and applied to varied aspects of the enterprise, including front-end conceptual processes, systems engineering, and financial functions.

In addition to IDS as an element of structural capital with unique capabilities, the IDS pilot programs also illustrate the effectiveness of using human capital in innovative ways. Engineers, serving as programmers, drew upon their experience base to develop tools for design. The end-product embodied sector-specific knowledge that could not have been created or adequately captured by outsiders. By coming from the end-user community, IDS engineers also understood the needs of the internal clients and "spoke their language", factors which probably enhanced their credibility and created a greater degree of acceptance.

IDS embodies a number of concepts for developing structural capital by automating processes, capturing design knowledge, and codifying a kaizen process that enables iterative improvement in design. The case study highlights how creating powerful IT-based tools and processes – and developing innovative structural capital – can create value by maximizing knowledge capture and re-use throughout the enterprise.

## 5.6. *Case Study E: New avionics for commercial aircraft*

Case study E examines a project by an aircraft manufacturer to integrate new avionics into existing commercial product lines. Originally developed for military aircraft, the new cockpit functionality and supporting components were beginning to penetrate the commercial airline marketplace. Company E, the manufacturer of a number of aircraft platforms, did not offer the device as part of its standard product line.

Over the last five years, however, commercial airlines began to request this new capability when placing aircraft orders. Initial installations were receiving strongly positive reviews from commercial pilots, and studies showed that the presence of this technology reduced the rates for reported "incidents" and minor accidents. To satisfy pilot demand and increase aircraft safety, a number of airlines began to request the avionics package as standard equipment on new orders.

Initially, one of the component suppliers began to offer this new equipment as an aftermarket addition; the avionics package was installed immediately after completed products were rolled off the line, to support their clients needs. Responding to requests from some of their preferred clients, Company G agreed to incorporate provisions and electronic components during the build process and began to install the system on the production line. However, the systems were still treated as exogenous hardware, with management considering the avionics package to be buyer-furnished equipment and not part of the company's area of responsibility. This attitude became harder to maintain as client requests increased. Installation of the BFE equipment eventually reached 50% of the fleet for Company E's highest-volume platform -- a strong indicator that the avionics package was a value-added component for a significant portion of the platform client base.

The increasing number of installations was also a point of concern on the shop floor. Production line teams had a learning curve associated with hardware installation requirements and there were no robust processes in place to deal with BFE installations of this type. In addition the avionics systems came from multiplier suppliers, with non-standardized components and a low degree of commonality. Processes, tools, and acceptance test criteria were either missing or unclear during the initial installation phase for each suppliers system. Each new configuration resulted in a new and potentially complex installation, and was viewed as disruptive to the production process. Engineers recall that the feedback from the shop floor was loud and clear: the new instrumentation was "killing us", impacting workflow and delaying delivery schedules for aircraft.

In response, Company E initiated a project to increase commonality in the avionics and mounting provisions in order to reduce production line variability. First, a business case was developed by an internal group of strategic analysts. Cost and revenue models were generated, with the findings presented to senior management. After approval of the concept, a project team was formed to implement the changes on the largest-volume product line. Working with suppliers, the project goal was to establish common packaging, features, specifications, and functionality for the avionics. On the cockpit side, Company E began to develop a common provision and interface for the avionics systems, with the goal of achieving commonality on all platforms. To support this process, factory floor tools and procedures would need to be developed to streamline installation and qualification. With the benefits of commonality and lower costs, Company E hoped to offer the systems as a packaged, optional feature on its product line.

The case study examined two aspects of the product development process in detail:
- The development of the initial business case for the project.
- Project execution, including collaboration with avionics suppliers to promote commonality, the re-design of cockpit provisions, and implementation on the aircraft production lines.

### *5.6.1. Project Goals and Implementation*

The business case for the avionics project was first developed by an internal strategic analysis group. The strategy group was originally formed after "golden handshake" retirement packages in 1995 led to a loss of senior staff. Realizing that significant intellectual capital and "tribal knowledge" had went out the door, senior management formed a small strategy group to focus on operational issues and new technology implementation in the existing product lines. The group primarily consisted of engineers and financial analysts with extensive experience in the firm, possessing a strong operational understanding of the organization. The mandate of the group was to incubate ideas, investigate possible business cases, and develop the cost and revenue models needed for business case evaluation. As a goal, the group tried to link new technology strategy to platform strategy and implement new ideas corporate-wide.

The strategy group relied on a range of skills and techniques to develop business cases. Revenue models were based on a market assessment, which involved collecting data on trends and querying clients about their long-term intentions. Cost projections involved determining recurring and non-recurring costs; since "time is money", these estimates were highly dependent on assumptions about the time required to redesign the cockpit provisions and integrate the new technology into the platforms. For the proposed avionics project, the group first worked with suppliers to understand non-recurring engineering costs and volume hardware costs for the systems. The strategy group also collected data from internal functions about the costs of in-production and retrofit installations, and extended the cost & revenue models to include other platforms. The process involved data collection from multiple sources within the organization to get good cost estimates. One analyst emphasized the importance of multiple sources: "Due to complexity of programs and subdivision of tasks, one person just doesn't know enough to give a complete financial picture."

When developing financial models from the collected data, the strategy group also needed to consider corporate biases towards overestimating task complexity and manloading requirements. Functional managers tended to be risk-adverse, especially when generating cost estimates about unfamiliar hardware or novel projects. Accordingly, manloading estimates were often dramatically conservative. An analyst with engineering experience said that functional managers tended to "pile it on. If you do a little reverse math, you find that the manloading is absurd... it's all about preserving their organization." Another analyst complained: "we're making estimates based on estimates, not on solid feedback on project financials." Group analysts were faced with incomplete breakdowns of cost reporting data from similar projects, and often had to rely on rough estimates about the actual allocation of resources and their associated costs for new technology integration projects.

Minimizing the margin of error in the financial models was a prime concern for the analysts. Assumptions about the degree of invasiveness of the technology, the potential changes required, and the resulting integration costs could all be subject to large error bars. The inherent uncertainty in these projections did not promote confidence or management support for strategic recommendations. Analysts characterized the corporate management as risk-adverse, given the large commitments of capital needed to build products with razor-thin profit margins. Accordingly, the senior management of Company E was reluctant to make decisions based on data with an acknowledged degree of uncertainty. For example, cost model results were often presented in a probabilistic format, with a range of values and associated confidence values; one analyst commented that this reporting style was "not part of the corporate language" at Company E.

To address these concerns, the analysts employed a number of approaches, including:

- Identifying the most critical factors in the cost and revenue models, and "sweating the details" to reduce uncertainty in these drivers.
- Openly acknowledging unknown factors in the models
- Collect follow-up data on past projects to compare model predictions to actual results
- Widely distribute their analyses to foster visibility and awareness in the organization

Although it was unlikely to allay all fears, these activities were meant to build credibility and legitimacy for the strategic recommendations of the group.

For the avionics project, the strategy group compiled the data and presented an analysis to senior management showing a positive net-present-value and healthy profitability for the project. The plan for the project was approved after review by senior management, and a project team was formed to develop commonality and plans for implementation in the production facility. The team involved about 15 personnel, with representatives from the impacted functions including flight deck design, forward cabin integration, systems design, test & validation, and business operations. Project managers also included suppliers in all team activities. To validate proposed design changes, pilots from the Crew Operations department were used for human factors testing and to get feedback from the end-user community. To understand the impact of these design changes, the team also sought the involvement of manufacturing engineers, tooling specialists, and factory floor representatives. A project engineer recalled that implementing the avionics package involved input from 17 different functional groups – a testament to the interconnectivity of complex aerospace products.

In order to integrate the avionics system into the production lines, suppliers would need to increase the level of commonality between their products. Two suppliers were approached to partner in the project and develop standardized packaging, functionality, and electronics interfaces. After some consideration, the suppliers viewed the potential project as a "win-win" arrangement. Increased commonality would establish their product as factory-installed options, could promote the penetration of their product into other aircraft platforms, and result in increased overall sales. After negotiations, a contractual agreement was reached where the suppliers would commit to paying some of Company E's non-recurring costs in order to secure exclusive rights to provide their avionics system. The project manager of Company E described these contributions to the NRE cost as "significant", and helped to build "critical mass" for promoting the program within the company.

Although both suppliers felt that the project would enhance sales, their enthusiasm was tempered by concerns about competitive advantage. The contractual arrangement included agreements about supplier proprietary material and the sharing of data. At first, technical exchange and knowledge transfer with suppliers was limited to a need-to-know basis of top-level performance specifications. In the beginning of project, Company E sat down with both suppliers together to develop design requirements and integrate tasks with the program schedule. Importantly, the involvement of two competing suppliers caused numerous difficulties with reaching design consensus and the sharing of data. Suppliers were not only concerned about proprietary data and areas of technical excellence, but were sensitive to any comparison between products or corporate design philosophies. Each supplier was fearful that their product would be perceived as having operational shortcomings that would indicate a lack of corporate capability and divulge areas of weakness to their competition. One lead engineer complained that these concerns made it "difficult to get any feedback about requirements from the suppliers in a timely manner."

Over the course of the project, engineers at Company E acknowledged having developed a stronger working relationship with one of the avionics suppliers than the other. The supplier that was geographically closer had assigned a corporate representative to the project with prior experience as an employee at Company E. Serving as a translator or "boundary spanner" between the firms, the representative facilitated in collaborative design meetings and helped foster a higher degree of trust between the supplier and the firm. Compared to the other supplier, the local firm was more responsive to requests for data and had established a higher degree of goodwill with the project team. The importance of this relational capital is difficult to gauge, but as one marketing representative noted, "in the end, if you have competing products with little differentiation, then you buy from someone you like".

The responsibility for coordinating and mediating between the suppliers rested on the project manager for Company E. The project manager was given broad authority to run the project; this included the authority to negotiate, contract, sign, and implement arrangements with suppliers. As an intermediary, Company E's project manager found it challenging to play the role of "gatekeeper" between two suppliers, having to protect proprietary data and foster cooperation between suppliers. The project had no collaborative tools for concurrent design with external suppliers, so supplier coordination and integration was an iterative, time intensive task. Issue resolution between suppliers and the firm relied primarily on the negotiation and trust-building skills of the project manager – his ability to persuade a supplier to "open their kimono" and share information about supplier processes, detailed technical knowledge, and production cost drivers. When queried about the skills needed for effective project management, the manager identified:

- A breadth of experience in technical project management. Although the complexity of tasks in aerospace projects tended towards the development of specialized skills, project management required a generalist's approach and the ability to see the "big picture".
- Visualization skills to develop novel paths between problems and solutions. It was necessary to "use intuition to come up with reasonable answers to complex problems."
- A personality that was not risk-adverse. A project manager "needed to feel comfortable walking an uncertain path."
- Social skill development, including the ability to "persuade, convince, and inspire" both internal and external stakeholders.

The manager commented that, although there was some corporate recognition of the necessary skill set for project management, there was no formalized training within the organization for developing these "soft" skills. In the manager's words, the project required "the building of relationships as well as processes."

### *5.6.2. Challenges*

Within the company, the project manager faced equally difficult challenges in aligning internal stakeholders and implementing the project in different aircraft business units. Responses from platform managers to the implementation plan were mixed. The project did receive strong support from the highest-volume platform. Since the avionics package was already widely adopted on this aircraft, the business case was well established and posed little risk to the platform manager. With support from both management and the shop floor, changes were rapidly undertaken to design a common provision in the cockpit, standardize the hardware, and develop shop floor processes.

However, a number of the other aircraft platforms did not immediately adopt and implement the project. For some of the platform managers, the avionics project was perceived as an unknown entity with no established track record on their product lines. The new technology was "not invented here", and managers were uncertain that the business case was valid for their platform. Although some client demand existed, the possible gain in revenue for the platform was perceived as small compared to the potential cost impact of disruptions on the shop floor. Since each platform served as an independent profit center, the platform manager's primary responsibility was to maximize profitability of their line; in effect, there was a lack of goal congruence between the platforms and the corporate strategy. Accordingly, the new avionics package was perceived as a corporate-sponsored project that did not immediately "fit" with their own platform goals.

The result was a slow pace for adopting and implementing the new technology project corporate-wide. A strategy analyst commented that the platform managers initially criticized the cost modeling and NRE estimates, but that surprisingly, "no one pushed back hard" and formally opposed the project. Instead, the project was relegated to back-burner status on some of the platforms, possibly with the intention of delaying implementation and waiting until upper management forgot or lost interest in the project. Without a strong push from corporate management, these programs progressed very slowly. One project manager noted that it could take 2-3 years to overcome organizational inertia and "close the loop" between corporate management and product line managers.

As the project progressed on the high-volume product line, the design team was also surprised by the difficulties in validating specific performance parameters of the avionics systems installation. Despite warnings from the suppliers, the project team underestimated the complex installation and testing requirements to validate the installed system. The lack of clear acceptance test procedures from the supplier also exacerbated this problem. After a number of installations were made on the high-volume platform, negative feedback from airlines and unhappy end-users led to a round of finger pointing between suppliers and the firm. Outside of an "out-of-the-box" component failure, the responsibility for problems with installed units was unclear. However, the corporate commitment to customer satisfaction dictated that, regardless of the fault, the units had "become the company's problem." With input from the suppliers, Company E revised the tooling and processes for shop-floor installation and acceptance testing. Tolerance budgets were re-allocated between supplier components and mounting provisions in the cockpit, requiring a few iterations with designers and suppliers to finally resolve the problem. This resulted in the delay of some project deliverables, including formal test and validation plans, until after the initial avionics packages were already installed and delivered to clients.

Finally, the project team was surprised by the complexity of the FAA certification requirements associated with the hardware changes to the flight deck. The avionic systems had always been installed under a "supplemental type" certification as an add-on product (aftermarket), which was always secured by the supplier. However, Company E was also responsible for a second certification that ensured the safe implementation of the avionics package into the flight deck. This systems-level certification addressed how the components affected operations in the cockpit, in order to assure that there was no compromise of safety or functionality. Although a FAA-certified design engineering representative (DER) was assigned early in the project, the design team underestimated the myriad of ways that the equipment could potential impact flight operations for the crew. In addition, a separate certification process was necessary for each minor variant of the product line, a requirement that was not well understood. Although the package and its installation were both eventually certified, the process took much longer and required more manhours than expected.

#### *5.6.3. Findings*

To date, the project has been fully implemented in one platform, with standardized avionics packages from the suppliers, a common provision in the cockpit, and production line processes for installation and certification. The project has not been widely adopted on other platforms, and has received limited support from some platform managers and chief platform engineers.

One of the lessons learned from this case study is the importance of internal alignment in order to mobilize corporate resources. Project managers found it difficult to convince each platform to change established processes and work together to carry out corporate strategy. Two factors contributed to this organizational resistance:

- Platform managers were given a degree of autonomy to operate their business units as they saw fit. In this sense, each product platform operated as a fiefdom in the larger organization, prioritizing their efforts to maximize the profit of their individual business unit.
- Although they agreed to adopt the new program, corporate management did not maintain a commitment to actively support and champion the project in each platform. Without pressure from above to make the project a corporate priority, the redesign of provisions and installation processes has not rapidly progressed.

In effect, the firm was missing some elements of structural capital for mobilizing resources behind corporate strategic goals. Given the lack of goal congruence and management support, the project was essentially missing the capability to align internal stakeholders. As a first step, this capability could be enabled by articulating how the project would create value for the firm and why the project was adopted as corporate strategy. Next, organizational incentives must exist to motivate the platforms to adopt the project and commit resources to the effort. Finally, management support must be consistent in advocating the project throughout the company. In the avionics case, these enabling factors were clearly missing.

The case study also highlights the importance of relational capital in new product development. Company E needed to work closely with key external suppliers, and enter into partnerships to deliver a value-added solution to their clients. Many aerospace projects are plagued by unhealthy dynamics in their prime contractor-subcontractor relationships, where subcontractors are "squeezed" to perform for as little money as possible. In this case, firms recognized the value in a collaborative effort, and were willing to revise designs and exchange detailed product information to create a better solution for clients. Communication and trust between counterparts at each firm were enablers that helped build critical, lasting relational capital over the course of the project.

Finally, the case study highlights how Company E utilized aspects of human capital, structural capital, and relational capital to successfully implement the project in one of its product lines. Some of the "lessons learned" from the case study are:

- The importance of intellectual capital in front-end processes, including the ability to build a business case and create validated financial models, for building consensus behind a new project.
- The role of intangible project manager skills, including persuasion, negotiation, and consensus building, to motivate both internal and external stakeholders.
- The coordination of interdisciplinary skills required to redesign cockpit provisions and modify shop floor processes for the new instrumentation.
- The need to understand the regulatory environment to avoid program delays.
- The important roles of client "pull" and prior experiences with new instrumentation in overcoming organizational resistance to change.

## 5.7. *Case Study F: Lease of military aircraft to a foreign country*

This case study examines a project for the leasing of military aircraft to a foreign country. The company had designed and manufactured the aircraft for U.S. military clients, but sought to develop additional markets overseas. The study looks at the firm's efforts to create a cost-effective product for foreign sales or leasing, including maintenance and support services for the aircraft. After investigating various approaches for reducing cost, managers at the firm developed a unique partnership with its U.S. military sponsor. In exchange for a pro-rated fee, they offered to include the foreign aircraft in the U.S. support infrastructure for servicing and life-cycle support. This arrangement dramatically reduced the package cost for the foreign client, and led to the creation of an innovative three-way team to work out details and deliver the first aircraft in one year's time.

The case study looks at the role of intellectual capital in the business case development and product development processes. Managers at the firm used a range of resources for identifying client needs and crafting a business plan that satisfied all stakeholder requirements. In particular, the study looks at the role that human and structural capital played in developing the lease, its creative support arrangement, and manufacturing processes that helped the firm execute and perform on schedule. The study also highlights how the relationship between the firm and its military client was leveraged to create a unique product support capability – resulting in a competitive advantage that made the project financially viable. The study looks at the important role of relational capital in forging alliances, translating knowledge across cultural and organizational boundaries, and overcoming regulatory hurdles for aircraft export. As a result of the project, the contractor was forced to learn, adapt, and develop new capabilities that helped expand its product line and establish a foothold into foreign leases and sales of its aircraft.

### 5.7.1. *Project Goals and Implementation*

For a number of years, the firm considered increasing their sales by expanding into international markets. In addition to developing relationships with potential clients for foreign military sales, management faced a number of regulatory hurdles, both domestically and overseas, that needed to be overcome. Some years earlier, the firm started an internally-funded business development effort, and began preliminary discussions with a foreign government about possible aircraft purchases. In the late 1990s, as business prospects improved, the firm's management began to commit more corporate resources to the project, assigning some of their business development staff overseas. These early efforts began to pay off when the foreign client issued a request-for-proposal (RFP), with the goal of either leasing or purchasing aircraft with the needed strategic capability.

After reviewing the initial proposals, the client concluded that none of the proposed solutions were financially viable. In particular, the firm's proposed costs for maintenance and support – which accounted for almost half of the contract value – contributed to making the package unaffordable. For the foreign client, it was too costly to develop a maintenance infrastructure to support only a small fleet of aircraft; an alternative would need to be found that would significantly cut the support costs for purchased or leased aircraft.

A solution was discovered by leveraging the firm's all-important relational capital with its U.S. client. In the past, the firm had worked with its client and the systems program office (SPO) to explore innovative arrangements for reducing program costs. These efforts included a sustainment program that sought to provide full life-cycle services for the aircraft, including contractor-provided turnkey support for repair orders, maintenance, and inventory management. These programs were enabled by an established track record on previous contractors, and led to a unique, non-adversarial relationship between the contractor and its military customer. Importantly, this relational capital could be used to craft an innovative partnership that would combine capabilities and provide a competitive advantage for the firm. Officials and senior management were willing to collaborate to find cost-effective solutions that would create value for both parties – that is, a true "win-win" solution. This cooperative relationship between the contractor and its client was a critical factor in the project, allowing the firm to reinvestigate whether any creative arrangements could be found for reducing program costs.

To create a vehicle for this relational capital, the firm invited both domestic and overseas stakeholders to form a working group. After some discussions between the contractor and the military clients, an integrated project team (IPT) was jointly formed in 1999 at the senior manager level, tasked with investigating possible solutions, their costs, and the regulatory issues that would need to be addressed. An executive steering group of high-ranking officials was also formed to provide oversight and input to the IPT, as well as to ensure the participation and involvement of key decision makers. To support the investigation, analysts and senior managers in the IPT began to jointly develop cost models, identify drivers, and explore possible trade-offs. This cooperative effort was important in building trust amongst the stakeholders, especially since the foreign client's previous experience with the purchase of foreign military aircraft was plagued with late deliveries.

A breakthrough occurred when members of the working group agreed on sharing the U.S. support infrastructure in order to cut costs. Under the arrangement, the foreign client would pay a fee to participate in the existing U.S. maintenance and support system. Rather than duplicating resources, the client would have access to inventory, maintenance services, and support equipment, all of which would be shared between the armed branches. The pro-rated fee would be used as a contribution to purchase spares and support equipment, effectively transforming U.S. support capabilities into a "pooled" resource. This creative solution allowed the foreign client to have rigorous support capabilities with lower operating costs, and reduced by almost half the price of the package.

With these savings, the foreign client agreed to lease the aircraft for seven years, with an option to extend the lease. Leasing the aircraft was preferred since it provided short-term capabilities, turnkey support, and the option to investigate alternative sources at a later date. The lease contract called for an aggressive delivery schedule, including the resolution of all regulatory issues and first-article delivery in one year's time. For the contractor, the schedule required managers to re-allocate existing resources for design modification and aircraft manufacturing to assure an on-time delivery. However, the project's regulatory issues required the firm to rapidly develop a new set of resources, both internally and externally. The quick resolution of regulatory issues would require new structural and relational capital – assets which are normally developed over longer time spans.

Domestically, corporate executives needed to receive federal approval for the lease of military hardware under export control. The firm required State Department approval for export, as well as to permit the client to receive data on military aircraft qualification in support of the certification process. In addition to navigating the maze of highly technical federal regulations, congressional approval would be needed for legislative changes that permitted the foreign leasing and innovative support arrangements for the aircraft.

Overseas, the firm also needed to understand and quickly gauge the magnitude of the foreign customer's regulatory requirements for the aircraft. Despite its demonstrated track record in the U.S. military fleet, the aircraft had to be certified as "airworthy" and obtain release by the foreign defense agency, an entirely alien process to the project staff. Since failure to procure this release could be a cause for termination of the contract, managers aptly considered this to be a high-risk item for the project. Having no prior experience with foreign regulations, the project team first tapped corporate knowledge from other divisions with military sales to the country. Intra-corporate knowledge was an important resource for the project, as managers also drew upon other divisions for aid in developing the capital financing and lease arrangements in the contract.

To better coordinate with overseas regulatory agencies, the firm also co-located more engineers at the client location, supplementing its original overseas business development staff. Later in the contract, the defense agency reciprocated by providing a staff member on a part-time basis to support the program. These staff members developed strong relationships with their counterparts, working to understand requirements and provide the necessary functionality to meet client needs. External resources, including a consultant with former experience in the foreign defense agency, were also utilized to span boundaries and understand the regulatory process. The firm used these varied resources to identify stakeholders and understand their underlying value propositions, hoping to avoid any surprises in the regulatory process.

### *5.7.2. Challenges*

Even with these resources, one of the biggest difficulties was satisfying the client's domestic requirements for aircraft safety. Staff engineers were familiar with the formal requirements of the U.S. safety certification process, which often took years to complete. However, the shortened process of the foreign client, rife with organizational and cultural differences, caused some confusion in the early stages of the project. In particular, a key component of the client's certification process was a document that presented a justification of the aircraft's safety. Rather than satisfying formalized requirements and specifications, this document needed to present a broad argument and supporting data that asserted that the aircraft was safe. By U.S. standards, the firm's engineers found that the document guidelines were vague and subject to interpretation, perhaps to allow regulators a large degree of subjectivity in determining air worthiness. To complicate matters, proprietary concerns prohibited engineers from looking at previous documents for other aircraft. At times, the process seemed vague and undefined; one engineer commented that developing the safety document "was like reading a novel – you won't really know if it's good until you get to the end."

To speed up the progress, engineers worked with the staff on loan from the foreign defense agency to span boundaries and understand the subtle points in the safety certification process. With his help, engineers were able to create a detailed outline of the safety document that satisfied all parties involved. With a draft in hand, the project teams used this boundary object to translate requirements and promote dialogue between the organizations. The use of both boundary objects and a boundary spanner helped lead to a change in the relational dynamics, as counterparts in the two organizations were more willing to compromise and find acceptable solutions. After numerous iterations on the safety document, engineering counterparts were able to overcome organizational resistance to change, gradually develop buy-in to the document, and satisfy the certification requirements for the aircraft.

To execute on the program, the firm relied on the human and structural capital built over years of manufacturing for U.S. military clients. Human capital included the IPT staff, many with a background as military end users of the product, and a management team experienced in business development. With a strong track record of staff retention, most knowledge on the company's programs was tied to the staff's continuity of experience; although a wealth of documentation existed on previous programs, only a portion was accessible online. Managers needed to know "who to tap" for details on aircraft safety issues and aircraft design. The project also received strong support from the corporate senior management, who were involved as needed, attended program status briefings, and met with the foreign program leads every three months.

The firm also used its extensive structural capital to execute and deliver on the project, employing long-established tools developed on previous contracts. Over the years, the firm had refined a process-based approach to product development, manufacturing, and project management. Under this approach, existing processes were systematically documented, analyzed, and refined to improve the quality of the product, with the use of formalized performance metrics – both financial and non-financial – to gauge progress and process improvement. For its U.S. client, the firm used these resources to assess program status, fix problems, improve processes, and iteratively converge towards implementing lean manufacturing on the shop floor. For this project, a similar process-based conceptual approach was used for strategic planning, business development, and early product development. These processes represented a wealth of intellectual capital that had been captured and embodied into a formal system for product development. Staff members were able to re-use the processes developed for U.S. military clients, or modify them to fit the new client's needs. For example, processes were tuned to match the client's "way of doing things", with reporting and the project's risk management approach tailored to match the client's preferences.

### *5.7.3. Findings*

By using this process-based approach, the firm was able to employ its structural capital, in the form of tools and formalized processes, to deliver the first aircraft after one year under contract. In addition to the importance of established structural capital, the case study emphasizes the critical role of relational capital in new product development. In particular, it highlights the importance of cooperative relationships between a contractor and its clients. Both the firm and its military clients were willing to explore atypical arrangements that maximized value for all stakeholders. Based on trust and an established record of past performance, the firm was able to use its strong working relationship with its military client as a source of competitive advantage. This willingness to collaborate, form a team, and share support capabilities represented a form of relational capital, forged over many years, which enabled the project to succeed.

Leadership also played a crucial role in forming the innovative teaming approach to the project. Advocacy from the top of the organizations, including senior executives and officials from the military acquisition functions, was important in promoting innovation in organizations that often resist change. The use of steering groups and executive IPTs also helped to establish relationships, build consensus, promote visibility, and signal the importance of the project throughout each organization.

The case study also showed the importance of relational capital in resolving regulatory issues. Although managers initially underestimated the magnitude of the task, they were able to quickly build working relationships that helped span boundaries and overcome regulatory hurdles. Using co-located staff and experienced consultants, the firm was able to bridge cultural and organizational differences, develop common terminology, and reach consensus with regulatory agencies on safety requirements. Relational assets ended up playing as large a role, if not greater, in certifying the aircraft as the underlying technology.

A final lesson learned from the project was the need to incorporate flexibility into corporate processes, including a corporate culture that could overcome organizational resistance to change. Some team members noted that, as a result of extended programs with U.S. military clients, the company had established ways of doing business that was not conducive to new clients and foreign military sales. The new project forced managers and staff to re-examine both tacit and explicit assumptions about business processes, and question the rationales behind why things are done. In a quest for customer satisfaction, processes needed to be flexible to allow for multiple clients, multiple configurations, and potential product derivatives in the future.

## *5.8. Case Study G: New line of commercial satellites*

Case Study G investigates the development of a new product line at a firm with extensive experience in building satellites for the commercial communications market. The product represented a significant departure for the firm from previous satellite development, with new challenges in technology, application, and a high degree of partnering with other firms.

To complete the project, the firm entered into a consortium of international companies to develop the satellite platform, provide the needed skills and services, and raise capital for the program. At an operations level, Company G assumed the role of satellite designer, prime contractor, and systems integrator to coordinate the design and fabrication work of all partners. At a financial level, the firm was a major investor in the spin-off entity, which provided a strong incentive for achieving overall project success. These dual roles – simultaneously serving as both contractor and client – led to an unusual product development process where many established business processes were altered to minimize schedule and maximize project success.

Technology requirements were also fundamentally different for this project. Before, the company had designed and built more than 100 satellites, most of which were product derivatives or built upon previous satellite bus designs. Most work was now for commercial clients, as senior management had successfully transitioned the business from its early days of exclusively government contract work. In addition to building commercial communication satellites, the firm often functioned as the systems integrator, providing launch services and operational support. Clients typically contracted for customization of an existing satellite product line, as most commercial customers required a rapid development schedule to fit the needs of their business case. This project, however, needed a novel platform that was unlike any of the company's previous product lines, utilized no existing components, and yet still required rapid delivery.

These changes forced the firm to establish new ways of utilizing its human capital, structural capital, and relational capital to achieve project goals. The case study looks at how Company G extended its knowledge base, established necessary relationships, and coordinated the efforts of multiple partners to develop a design that met the evolving needs of the project.

### *5.8.1. Project Goals and Implementation*

The idea for the satellite project had originated in-house many years earlier, with the conceptual work initially funded on internal R&D dollars. At the time, a lack of interest from senior management prevented the project from maturing beyond the early conceptual phase. In the early 1990's, the concept was rejuvenated with a change in the corporate management team and the promotion of project advocates. After examining possible business scenarios, it was decided to spin-off the project, create a new entity, and partner with 6 firms to provide seed funding and resources for the effort.

Contractually, an atypical arrangement was crafted to satisfy the business model. The project was spun-off, with the new company populated mostly with staff from the principal partners. The new company served as the client, with responsibilities for developing requirements and overseeing the program. The spin-off would eventually be responsible for establishing the commercial business and providing ground support and systems operations, while the contracted firms would provide the necessary hardware and launch services to create the system. Investment in the new entity was not only a prerequisite for receiving subcontract work, but each partner also received subcontract work roughly in proportion to their contributed percentage. All partners, therefore, had strong incentives to perform in their role as contractor, and assured that each firm stayed focused and aligned on delivering client value. Operationally, the international partnership posed a number of dilemmas, including:

- Coordinating firms with distributed responsibilities for design and fabrication.
- The challenge of distributing workshare based on level-of-investment, not on the capabilities of each firm.
- The difficulties of coordination and management of numerous partnering firms.
- Managing the efforts of a global team and supply chain spanning 20 time zones

Company G, as prime contractor for satellite development and lead member of the team, assumed many of the systems engineering responsibilities for the entire program. Initially, this involved an evaluation and ranking of the skill sets of the partners, and a division of tasks to take advantage of core competencies. Relationships needed to be formed, and delicate negotiations were needed to assess skills and determine roles for the investing partners. In order to incorporate some firms in the project, make-or-buy decisions were driven by the need to share and distribute work. After an initial "shakedown" period of about 6 months, Company G was able to review the initial performance of the team members, identify areas where gaps and weaknesses existed, and negotiate changes to the workshare distribution.

To accelerate the product development process, Company G initiated a co-located design effort to get the project underway. Each partner provided a design team to Company G for the first 18 months, with all teams co-located in a new facility. With about 125 engineers on-site, the teams worked side-by-side and established a concurrent engineering environment during early product development. Besides having dedicated meetings for coordination between groups, the teams were integrated and involved in most of Company G's internal meetings to promote open communication between all partners. Importantly, each team also was empowered with the task of drafting their own initial specifications, which were later revisited and updated after the PDR.

Co-location also had a self-reinforcing effect to incentivize and motivate the design teams. As an international partnership with a high degree of visibility, the project became a source of corporate pride for each team. Since the closely working teams were co-located at one site, there was an awareness of the progress and critical issues associated with each team's performance. Given this visibility, engineering teams were determined to "hold up their end of the bargain" and develop high-quality, timely designs. For many teams, this motivation extended further to a sense of national pride and friendly competition between perceived international rivals. These dynamics supplemented the financial incentives, created a sense of camaraderie and mutual effort, and helped foster trust amongst the project partners.

Later in the program, Company G also co-located some of its staff overseas to support and troubleshoot hardware integration. Engineers and managers were co-located with various teams, including the integration & test facilities, to provide experience and areas of strength where missing or needed. Co-location was considered one of the most efficient means of transferring design knowledge to the downstream processes.

The high degree of co-location was an important means to build relational capital for the project, and was considered essential during early design phase. All interviewees identified co-location as a critical success factor for the project; according to one manager, "co-location was crucial... especially since we were doing things on the fly. It was a dynamic environment with constantly changing requirements, and the design process was highly iterative. It couldn't have happened without co-locating the teams."

During the initial 18-month design period, each partnering firm committed to assigning high-performing, key engineers from their home organization to the co-located teams – a direct outgrowth of the financial incentives behind the program. Engineers from Company G described the co-located representatives as high quality, highly experienced engineers. In addition to providing needed human capital to the project, the assignment of high performers also helped to build credibility and legitimacy for the project after the teams dispersed and returned to their home organizations. Since co-located team leaders were typically senior in his/her organization, they served as empowered corporate leaders with the authority to shape manufacturing decisions after returning home. This helped firms to maintain focus and prioritization during the fabrication, integration & test phases of the program.

Similar to the other partners, Company G's management confirmed their commitment to program success by assigning the firm's high performers to the project. In contrast to the firm's financial investment, one senior engineer referred to this commitment as a form of "sweat equity" in the project. The project was staffed with a fully constituted team of senior engineers, systems engineers, and program managers, with the authority to assemble the best and brightest from within the company. Company G prided itself in having retained a high percentage of its experienced staff by maintaining a steady flow of commercial work over the years, and felt that it had a strong human capital base. The novelty of the project, however, was deemed a significant source of concern since the firm had no experience in designing a system for this particular application. Every subassembly needed to be redesigned or designed from scratch; when the design was finalized, no subassembly had been flown before on the firm's previous satellite products. In order to get a handle on a project so dramatically different from corporate experience, the company initially drew upon retired staff and industry consultants to help scope the effort. With the help of these "graybeards", the senior engineering staff performed trade studies to try and understand the potential ramifications of system architecture choices. The firm continued to use outside support during the design process to fill holes, provide needed expertise, and enhance its existing knowledge base.

Although new design capabilities needed to be developed, the firm could rely upon well-established processes for program management and managing complexity. Based on its extensive history building satellite platforms, Company G established a program management office to manage resources, coordinate partners, perform systems engineering and analysis, and develop product assurance plans. For this design effort, integrated project teams (IPTs) were assembled with engineers from all core functional units, thereby leveraging the sector-specific knowledge from other satellite products and their derivatives. To support the IPTs, Company G maintained the master schedule for the project and established a work breakdown structure that was linked to the schedule. Established processes were used for cost and schedule management, interface control, design reviews, document management, drawing sign-off and release, and management of shop floor activities.

Despite project novelty, the firm had the necessary management experience to estimate the scope of tasks and required manloading. When developing the schedule and critical milestones for design tasks, management used a formalized front-end process plan that drew upon its previous experience. Experience-validated data allowed managers to gauge tasks and estimate contingency margins for the new project. With an established management process, the lines of authority & responsibility were clearly drawn and permitted what one manager described as "autocratic" decision-making. Importantly, these managers were trusted figures from within the organization that could lead and motivate these teams. This leadership was further bolstered by a high degree of involvement by senior management, including an executive vice president who was dedicated to the program.

### *5.8.2. Challenges*

Despite a wealth of human capital, structural capital, and core competency in managing satellite development, the firm had to overcome two operational challenges:

- Collaboration and coordination in a multinational partnership.
- The dynamic nature of the program, with requirements that evolved and changed over the project cycle.

Although co-location led to the development of strong relational capital for the project, there were collaborative obstacles that needed to be overcome. For example, cultural differences related to business practices posed significant difficulties for the project. Partners approached their tasks with varying degrees of management control and oversight, which created coordination difficulties for a complex system. For example, firms had different perceptions about the role of the program manager: for some partners, the program manager had limited "hands-on" operational responsibilities and served strictly as a contractual interface. In some instances, it was necessary for Company G to transplant personnel into partner organizations to provide effective shop-floor management. Also troublesome were cultural tendencies towards conflict avoidance and the formal reporting of problems areas. Finally, one manager hinted that some partners worked well together, whereas others did not – a trait that was attributed to international "culture clash." In these instances, political negotiation and finesse was cited as a key skill to keep the project moving smoothly.

After the end of the co-located design phase, coordination and knowledge transfer became harder to achieve. Correspondence and data exchange with remote partners was mainly via phone and fax, with email attachments used later in the program. IT solutions which enable collaborative design were not yet mature in the early 1990s, and without widespread adoption of compatible solid-modeling CAD tools, data translation was often needed between partners. To coordinate efforts, managers cited daily phone conferences as the most effective management tool, with a series of calls made from 6am to 6pm to receive informal status reports and monitor critical path performance.

Surprisingly, the language barriers that existed between international partners were downplayed by most interviewees as a surmountable problem. English was used as the principal language on-site, and the internationally co-located staff were sufficiently fluent in the native language to function effectively. One engineering director even claimed that "technical literacy" was the true common language of the project, serving as a basis for communication beyond any cultural differences.

In addition to collaboration, the highly dynamic nature of the program created unusual challenges for Company G. Control and stability, not dynamic change, was the hallmark of the company's background as a satellite integrator. In the past, the corporate culture of the firm fostered a systematic approach to project control, redundancy, and risk reduction – typical traits for any firm that develops space flight hardware. From the start of the project, it became clear that flexibility and responsiveness to change would be equally important traits for this project. The first indication was early confusion about requirements and systems engineering responsibilities for the project. The client had been tasked with the initial definition of project requirements and specifications for the partners. Early in the project, it became clear that the client was insufficiently staffed to handle this task; first, the requirements for the project were unclear, except for the need for commercial viability. Second, the detailed specifications for the individual teams were inconsistent and unrealistic. One engineer commented: "when I read the specs, I knew there would be trouble. There was no clear flow-down from the requirements, and there was a severe lack of systems engineering. This simply won't work together."

As the lead team member and prime contractor, Company G's management chose to assume responsibility for most of the systems engineering tasks. It began to develop a consistent approach to requirements definition, their flow down to individual teams, and the development of specifications that were traceable to system requirements. The quest for a stable set of system-level requirements turned out to be elusive throughout the first three years of the project. For this project, the most critical requirement was a cost-effective solution that fit a frequently changing business model. The result was a highly dynamic, iterative process: as questions arose, cost-performance trade-offs were performed, with results then rationalized with the business model. Using the business model to predict system usage, traffic, and system-limiting "stress points", new requirements would be generated and flowed down to revised specifications. Requirements and specifications were also modified from the bottom up, as new technologies influenced the design and the results of engineering models changed the allocation of performance specifications. Thus, the requirements & specification process was in effect an ongoing negotiation, with issues that percolated up, were evaluated and negotiated, and then percolated back down to the design teams. "During this project, requirements were always being negotiated, and the specs were generated in real-time" according to a program manager.

This dynamic approach represented an entirely different way of doing business, and often rubbed against Company G's corporate culture to manage risk through stability. Most previous projects were designed, tested and managed methodically, with significant front-end preparation devoted to the development of stable requirements and specifications for the rest of the project. The business of building complex space-based systems had promoted a risk-adverse culture amongst some engineers, who viewed the lack of stable specifications and the fast clock speed of the project as "terrifying" at times. The demands of the schedule also reduced the time available for testing and qualifying flight hardware. Changes made in procedures about qualifying all flight hardware flew directly in the face of previous corporate philosophy, and caused what one manager described as "bloody fighting" internally during the early phases of the project.

To address these concerns, management adopted an approach that emphasized tight specifications and rigorous testing of components, with a slightly reduced reliance on systems testing in order to shorten the timeline at end of project. The philosophy was to "build quality in" with a modular approach to component designs, including qualification and testing of all subassemblies as the lowest level. All components were over-qualified and tightly spec'd to achieve the high reliability needed for space products. To validate the system design in a shortened schedule, the firm qualified functional portions of three separate satellite prototypes, which included thermal vacuum and vibration testing. This philosophy emphasized reliability at the component level, which would hopefully percolate up and result in steady performance at the integrated systems level. This approach served as a compromise that expedited the schedule while still leveraging the firm's experience and competency in building robustness and reliability into its products.

Finally, some risk associated with novel aspects of the system, especially those involving unknown environmental or operating conditions, was difficult to address during the product design phase. Wherever possible, a combination of modeling and prototype testing under simulated conditions was used to mitigate some of these risk factors. According to an engineering director, however, there were some risk factors that were difficult or impractical to reduce by testing or simulation. According to the director, "In the end, engineers must draw upon their prior experiences and their judgment about what will work" when mitigating risk in new product development.

### *5.8.3. Findings*

After 4 years of product design and development, Company G and its partners were able to deliver hardware and begin launch of the new satellite system. The approach to risk mitigation based on combining rigorous component testing, integrated systems testing, and simulation achieved the desired results: the system was deployed and operated as planned. Small performance variances resulting from non-critical design errors were discovered in early hardware and corrected in later units. After amassing thousands of hours of flight time to date, the hardware performance data has correlated well with the model predictions, and the satellite system has been operating well within its performance specifications.

The case study provides a number of insights about the intellectual capital needed to execute complex product development. Company G had many existing capabilities for satellite design and development. An extensive history of past projects, combined with personnel retention, allowed the firm to establish a strong base of staff experience. Supplemented by industry consultants, the firm had substantial sector-specific knowledge and human capital to perform many of the design tasks. In terms of structural capital, Company G had a wealth of established corporate processes for project management, hardware integration, and operational support of the product. The project also benefited from a high degree of internal support from senior management. These assets, however, were necessary but not sufficient for achieving project goals.

The success of the project hinged on relational capital, which enabled the project while posing some unusual challenges. The firm needed to rely heavily on external resources to both finance and execute the project. To accomplish this, they developed unique relationships and helped create a vehicle to organize and motivate the collaborative effort. By spinning off the project and entering into a partnership, they not only developed relational capital, but also established a means to incentivize and leverage it to achieve ambitious goals on an aggressive schedule. The partnering agreement had multiple effects:

- It provided the needed skill sets for project execution
- It attracted investment capital for the project
- It served as a motivating force for partners to perform above and beyond the letter of the contract

The agreement achieved the difficult goal of incorporated incentives for all partnering firms, and established organizational "buy-in" (both figuratively and financially) to the project. Since the corporate interests of these firms were aligned, the project could proceed with a common sense of commitment, including the willingness to allocate key personnel and resources

The partnership represented an entirely different way of doing business for Company G, and enabled collaborative behavior that could not have occurred otherwise. Given the close relationships between these firms, the arrangement led to a non-adversarial relationship between client and contractors, which one manager described as "incestuous" at times. Each firm's design staff was easily accessible for discussions about system requirements and the impact of proposed design changes. Partnering firms, along with the client were not only involved in formal design reviews, but often attended weekly meetings with design teams. When needed, the informality of this relationship permitted rapid changes in specifications without the burden of contractual modifications and formal changes of scope. This informality between partners and the client allowed the team members to remain focused on project goals, and helped to achieve a remarkable degree of alignment between contractor goals and client value.

The degree of co-location involved in this project is a strong testament to each of these firm's commitment. The protracted co-location period enabled Company G to expedite the design phase with a high degree of collaboration and cooperation. A common observation from many of the interviewees was the importance of co-location, including the camaraderie and close relationships that were formed, to the success of the project. Co-location enabled frequent knowledge transfer with fewer political obstacles, allowing for rapid iteration of designs and coordination of design efforts. This degree of relational capital stands out as a unique capability that enabled project performance in this case study.

The relationships between firms, the degree of co-location, and the alignment of goals with client value represent the key "lessons learned" from the project. These relationships did come with some cost: it required a global management system to coordinate designs and workflow throughout the project lifetime. Although it was a challenging task, Company G's experience in building and managing complex systems proved sufficient to overcome these obstacles.

## 6. Analysis

### *6.1. Findings from the case studies*

As a whole, the case studies provide a wide spectrum of product development projects – some in their early formative stages, and others that have reached project completion. In each case, a variety of corporate resources are brought to bear on different challenges, with various degrees of success in each project. So what do these cases tell us about intellectual capital and its use?

First, we need to highlight how intellectual capital – the knowledge-based assets of the firm – contributed to the product development process in these cases. Since product development is a highly creative and innovative process, it understandably relies heavily on these knowledge-based assets. Like all intangibles, these assets are also hard to pin down, difficult to identify, and almost impossible to value. However, by reviewing the cases in aggregate, we can see how human, structural, and relational capital contributed to the success or failure of the projects and, importantly, identify some common themes about their usage.

The case studies suggest that each type of intellectual capital plays a unique role in providing critical capabilities for product development. These capabilities – and whether they are absent or present – are the common threads in the case studies, often cited by managers as the decisive factors in achieving project goals. Rather than emphasizing specific intellectual assets, the cases reveal that there are common capabilities, derived from combinations of knowledge-based assets, which can make or break each project.

To organize these findings, a "capability matrix" has been created for each type of intellectual capital. Ranked by five levels, these matrices help document how improved capabilities led to project success in the cases, and where missing capabilities hindered some of the projects. In some cases, project teams with strong capabilities in one area were seriously derailed by missing capabilities in other areas. As a whole, the matrices show how these capabilities contribute to project success, and emphasize the importance of synergies that result from the right combination of human, structural, and relational capital.

### *6.2. Human capital*

One of the premises from the framework is that a company's human capital – its staff and the knowledge-based assets that they represent – are the central ingredients in the corporate recipe for product development and value creation. The findings from the case studies not only affirm the central importance of human capital, but also highlight important capabilities (mission-critical capabilities) that are derived from a firm's human capital assets. As seen in the case studies, human capital is the ubiquitous component that is a necessary – but not sufficient – condition for project success. When combined in the right mix, however, human capital provides a unique combination of skills and capabilities that complements the firm's structural and relational capital, serving as the "engine" that drives product development.

The trick for managers, of course, is to identify which of these capabilities are most important for successful product development. Looking at the common themes that were threaded through the case studies, some of the critical capabilities were based on:

- The quality of the staff's knowledge base, as indicated by their skills and experience.
- The ability to expand that knowledge base, through training, collaboration, and knowledge exchange. This ability requires a willingness to learn and develop new skills, combined with corporate programs that promote personal growth.
- The ability for firms to effectively use the human capital that it has, and procure the human capital that it needs.
- Explicitly, the human capital of the project management team. The intangible capabilities of managers, including their ability to lead, coordinate, inspire, and build consensus behind projects, is a crucial factor in many of the case studies.
- And finally, the senior corporate management and their contribution to human capital, including their degree of support and engagement in the project.

These human capital assets contribute to the project, through the ability to design, interact, communicate, and manage the product development effort. To organize these assets, the matrix in Figure 6.1 summarizes and ranks these capabilities on a worst-to-best grade. By examining and comparing the case studies, patterns begin to emerge about these critical capabilities and the underlying human capital that enables them. The cases show that strong performers have the right people, tools, and processes for leveraging their human capital, whereas some projects are hampered by missing capabilities in this area. These differences in capabilities form the basis of the matrix. By extending the range to worst-case and best-case scenarios, the matrix provides a wide spectrum of capabilities – and exemplifies how managers can improve their human capital utilization.

In the capability matrix, firms at Level 1 have minimal or limited capabilities, whereas Level 5 represents some of the best practices from the case studies. It was noted that firms with strong human capital have capabilities and processes that consistently fall at the upper levels of the matrices. The matrix therefore illustrates how managers can assess their skill base, and importantly, how additional human capital could be developed to enhance the success of their organizations.

### *6.2.1. Staff experience*

The principal indicator of a firm's knowledge base is the experience of its staff. Not surprisingly, every manager in the case studies pointed to the quality of their staff as a critical factor in determining the project outcome. Staff experience, measured by years in the industry, is often used by researchers and practitioners as a straightforward metric for the quality of the staff knowledge base. Combined with the levels of education of the staff, these metrics are frequently used as indicators of human capital – perhaps because they are also some of the easiest to measure.

**Figure 6-1 – Human Capital capability matrix**

| Ele. No. | Human Capital (HC) Metric | Capability Matrix | | | | |
|---|---|---|---|---|---|---|
| | | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
| 1 | Staff experience | • Staff has limited sector-specific experience in industry<br>• Highly novel project with no relevant corporate experience | • Most staff has sector-specific experience (>5yrs. in industry)<br>• Staff has only a few PD cycles under their belt | • Staff has both extensive industry experience and operational understanding of organization<br>• Staff has multiple PD projects under their belt<br>• Design staff has detailed knowledge of manufacturing issues | • Staff has interdisciplinary or cross-functional training for boundary spanning<br>• Capability gauging and "know what you don't know"<br>• Use of consultants and graybeards to acquire needed knowledge | • Staff has prior experience as a supplier or client<br>• Project populated with corporate high performers<br>• Dedicated teams for product development or business case development |
| 2 | Staff learning | • No company-sponsored mechanisms for staff learning<br>• Strong bias against technology "not-invented-here" | • Training and education encouraged, but limited in scope<br>• Some support for technical conferences and out-of-house knowledge exchange | • Frequent training and skill development<br>• Active participation in conferences and professional societies<br>• Ability to understand and incorporate complex out-of-house hardware | • Coaching and mentoring system for staff development<br>• Firm sponsors formal profession development programs<br>• Corporate training in team processes and collaboration<br>• Cross-functional training to develop expertise in new disciplines | • Specialized training and critical skill development at project kickoff<br>• Staff is self-initiated about learning and skill-set development<br>• Corporate training in "soft" skills (presentation, negotiation) and product realization (the art of project mgmt.) |
| 3 | Human Capital utilization | • Manpower shortage to accomplish project tasks<br>• High performers do not exist or are not accessible (working other projects) | • Project is well-populated with internal staff<br>• Little use or awareness of experts in other corporate divisions | • Corporate yellow pages for locating experts<br>• Funding for consultant support as needed | • Hyperlinked knowledge web for locating experts<br>• High staff retention rates, corporate ability to retain key staff after project completion<br>• High performers are available for project support | • Ability to pull staff from other divisions as needed<br>• Ability to easily access retired staff with heritage knowledge |
| 4 | Management support and involvement of senior management | • Project manager is new to or has limited understanding of organization<br>• Lack of senior management support of project | • Managers have difficulty marshalling resources behind project<br>• Minimal intervention or involvement at senior mgmt. level | • Managers able to network and communicate effectively in the organization<br>• Close ties between project mgmt. and senior management<br>• Project has "high visibility"<br>• Commitment of corporate resources by senior mgmt. | • Program manager has formally identified external stakeholders, works to build support for project<br>• Program manager has "power of persuasion" to build internal consensus<br>• Consistent advocacy and involvement of senior mgmt. | • Project "champion" at senior mgmt. level<br>• Active involvement of senior stakeholders in oversight/steering committee |

However, the interviewees also emphasized other characteristics about the skills and experience of their staff that enabled project success. In particular, five common themes appear in multiple cases in the study:

- *Staff with prior experience working for clients, suppliers, or partners.* Many managers pointed to the invaluable contribution from staff members with experience outside of the firm, especially those from "the other side of the fence". Staff members who were previously employed by clients, especially those that served in the military, provided critical insights into the client's organization and their underlying value proposition. In the aircraft derivative project (Case A), staff members brought both military and commercial sector experience to the project, allowing them to understand the needs of potential clients as well as existing stakeholders in the project. In the new avionics project (Case E) and the military instrumentation project (Case C), personnel with experience in manufacturing and the supply chain were important for spanning boundaries between the firms. In all of these cases, this cross-boundary experience – with the ability to "speak the language" of the client or supplier – was crucial in understanding how to craft a winning value proposition for the project.
- *Interdisciplinary experience.* Staff with experience in different functions (for example, the mechanical engineers with software programming experience in Case D) were able to use their unique insights to shorten development times in many of the projects. Interdisciplinary experience, similar to prior experience as a client, can enable staff members to create products and services that better meet the needs of their end users.
- *Organizational understanding.* Effective staff members typically displayed an operational understanding of "how things worked" at the firm and "how to get things done". This understanding of the organization and its culture was an important capability for staff members, allowing them to be effective actors within the firm. Although it is fostered by years of experience at a firm, it is worth noting that this capability is distinctly different than experience alone – some staff members have it, others don't. In a number of the cases, including the avionics project (Case E) and the software development project (Case D), the inability to navigate the organizational landscape was a limiting factor in achieving the widespread adoption of the program goals. Successful aerospace projects, with complex organizations and many internal stakeholders, particularly require this kind of organizational understanding.
- *Dedicated product development teams.* Projects born from an established product development function, comprised of team members that have worked together in the past, benefited from a higher experience base at the start of the project. Starting with a dedicated business case development team (avionics Case E) or an advanced systems design team (experimental aircraft Case B) gives the firm a "leg up" when kicking off a project.
- *Capability gauging.* In addition to a strong experience base, the case studies show that it's just as important to "know what you don't know". At both a personal and organizational level, staff must be aware of knowledge and experience shortcomings, as identifying missing human capital is the first step to filling these holes. This capability gauging in the commercial satellite (Case G) and experimental aircraft (Case B) projects allowed managers to boost their human capital base, either by hiring new staff or farming work out to partners or consultants early in the project.

### 6.2.2. *Staff learning*

Human capital is not a static stock. In addition to staff experience, companies must supplement and grow their knowledge base through training and staff development. Interviews from the case studies show that managers are concerned that their staff members stay current with the latest developments in their fields, especially since these product development projects often rely on cutting edge technologies.

In general, the challenge is not simply in providing educational opportunities for staff. The case studies suggest that staff learning requires not only training, but requires both a willingness to learn and a corporate culture that encourages individual growth. Some of the common themes from the cases include:

- *Rejecting the "not-invented-here" bias.* The success of many of the projects hinged on the ability to understand and incorporate complex hardware that was developed out-of-house. Frequently, this required both individuals and organizations to overcome their bias against technology that was "not invented here". In some examples, including the avionics (Case E) and the satellite (Case G) project, major hardware subassemblies were manufactured by either suppliers or partners. In the avionics case, this reluctance was a significant factor in the limited adoption of the program across the corporation. In the design software project (Case D), the product was developed in-house but met resistance from other functional groups in the organization. On the other hand, engineers in the experimental aircraft project (Case B) embraced new technologies as part of the project, incorporating out-of-house technologies and modeling tools into their conceptual designs.
- *Specialized training at project kick-off.* Projects that tried to boost staff knowledge early, such as the experimental aircraft project (Case B), were well positioned to develop new capabilities needed later for project execution. Of course, this pro-active approach to staff learning requires that managers can gauge their capabilities and identify shortcomings, as discussed in the previous section.
- *Training in "soft" skills.* Finally, some managers pointed out that staff training should not be limited to strictly technical capabilities. Training should also include so-called "soft" skills that are needed by staff to be effective agents in a corporate environment. Although many of the firms offer corporate training in team processes and collaboration, there was no consensus whether these efforts led to improved product development. At a managerial level, however, the avionics study (Case E) suggests that training is still needed in skills such as presentation, persuasion, and the art of negotiation.

As a whole, the case studies suggest that staff learning must be accompanied by a corporate culture that is willing to "try new things" and pursue unproven technologies. Given the high degree of novelty with product development projects, managers must balance their risk aversion with a willingness to consider "not-invented-here" technologies, despite the lack of experience that the firm may have with the technology. The cases seem to suggest that the climate for risk taking – and possibly failing – is often set by senior management at the firm and their degree of involvement in the project. In order to implement new technologies, staff members and managers must be willing to tread new ground and extend their knowledge base – which can be a tricky challenge in a risk-adverse corporate culture.

### *6.2.3. Human Capital utilization*

Having good people is not enough; like financial assets, human capital needs to be applied and leveraged effectively to create value. The case studies show that firms need to have capabilities for accessing and utilizing the knowledge that is embodied in its human capital. Managers need to "know what we know", with the ability to match program needs with the right personnel in the organization. This capability is partially embodied by human resource allocation and manpower planning, but the emphasis here is on the intangible knowledge that each staff member represents.

In the case studies, all firms have some type of tool in place to effectively use the human capital that it has, and to procure the human capital that it needs. The best tools provide the following capabilities:

- *Corporate yellow pages.* At the simplest level, many firms have identified staff members with special expertise in their domain, and have developed a directory or online database to access these individuals. Some of the projects, such as the military instrumentation program (Case C), use IT knowledge management systems that have searchable, hyperlinked knowledge "trees" that provide a means to both collect and access intangible knowledge from employees – especially as they retire or leave the company. These systems attempt to create a "knowledge web" for accessing corporate experience, helping to identify the right people with the right knowledge for the job. In the end, however, staff retention is the ultimate method for both maintaining and accessing human capital. This capability – to access what people know – was a common theme in the case studies.
- *Maintaining connections with former employees.* Also, a number of the projects benefited greatly from maintaining connections with previous staff members that had left the organization. In the experimental aircraft (Case B) and commercial satellite (Case G) projects, retired "graybeards" were retained as consultants and played major roles in the conceptual design of the hardware. Accessibility to a "deep bench" of former employees allows a firm to utilize years of experience that would otherwise be lost. Given the difficulty of retaining staff in today's workplace, companies have found that maintaining connections with these former employees is an important means to access old knowledge and supplement the human capital base.

### *6.2.4. Management skills*

A good staff must be led by a good management team. Although the skills and experience of the management team is simply a subset of the firm's human capital, the case studies suggest that the project manager plays a special role in the success or failure of product development projects. The skills of a good manager extend well beyond their ability to manage cost, schedule, and manloading. In particular, project managers pointed to intangible capabilities that dramatically influenced the success and failure of the projects, including:

- *The ability to marshal resources behind the project.* Managers need to pitch ideas, negotiate with stakeholders, and build internal consensus behind their projects. Often, these intangible skills are essential to getting the critical corporate resources needed for the projects. The case studies emphasize that managers need both a knowledge of the organization and the ability to "network" effectively to get things done. In the early stages of a project, such as the experimental aircraft effort (Case B), the project manager needs to build consensus simply to get the project off the ground. Later in the project, these intangible traits can take on many forms and are often difficult to define. The manager's "power to persuade" may also need to extend well beyond the local office, given the complexity and interdivisional nature of these aerospace projects. For example, in the case of the military instrumentation project (Case C), key members of the management team were transplanted from manufacturing divisions in the organization; their intangible skills and personal connections allowed them to successfully span boundaries and remotely coordinate efforts for the project.
- *Traits for coordinating and promoting collaborative work.* Project managers in the case studies stressed that intangible skills play a large role in leading and managing a project team. The ability to lead – including the building of confidence and trust – is an intangible skill that is extremely difficult to quantify. At a basic level, managers relied heavily on their communication skills, including the ability to articulate goals, requirements, and how the project fits with the overall corporate strategy. Managers also pointed to the importance of inspiring the workforce, retaining staff, fostering collaboration, and the need to have good skills at conflict resolution. As mentioned earlier, these "soft skills' are often not developed or only cursorily addressed in managerial training courses.

#### *6.2.5. Senior Management support*

Finally, the case studies substantiate that senior corporate management also play a large role in project success or failure. Two evident themes were:

- *Senior management's degree of support and engagement.* Projects where corporate managers were highly involved faired better than those with little involvement or support. Formal oversight committees, such as the steering committee in the military aircraft project (Case F), provided a useful vehicle for continued involvement of corporate managers and senior stakeholders, making sure that key decision-makers were aware of program status. When senior management is highly involved, projects profit from their expertise and insights from previous corporate programs. These projects also benefited from the close ties between project managers and senior management, making it easier to get critical corporate resources applied to the project.
- *Role of the project "champion".* In particular, some projects benefited greatly from having a strong advocate at the senior management level. In the military aircraft (Case F) and satellite projects (Case G), support and involvement at the corporate V.P. level assured that the needs of the program were treated with the highest priority. Consistent involvement also meant that the programs maintained their high "visibility", sending a signal throughout the organization of the importance of the project. Having a strong champion, therefore, can enable many of the other capabilities that allow a firm to effectively use its human capital.

In all, these findings show that human capital is more than the skills and experience of the workforce. Since human capital actually takes many shapes and forms, managers should consider which capabilities directly benefit their short-term operational needs, and which capabilities are also needed for their long-term strategic goals. To this end, the matrix in Figure 6.1 provides a starting point for managers to self-assess their human capital. Rather than simply "counting heads", the case studies suggest that successful projects require a truly multi-dimensional approach to managing intellectual capital – one that provides the right mix of capabilities for each project.

### *6.3. Structural capital*

In the case studies, firms also relied on different types of structural capital to leverage its human capital and develop new products. Structural capital – the knowledge-based infrastructure that represents their corporate "know-how" – allowed these firms to efficiently apply their past experience to new projects. Just like human capital, the cases show that structural capital can give a firm unique capabilities, and that these capabilities can allow design teams to:

- Access and use existing corporate knowledge
- Exchange and transfer knowledge with suppliers and between staff members
- Tap the staff's creativity with tools that help create new knowledge
- Provide a means to capture that knowledge for future projects

Basically, these corporate capabilities allow the firm to manipulate knowledge for its benefit. The cycle of knowledge retrieval, creation, and capture creates new structural capital – knowledge-based assets that are owned by the firm – that can serve as the "vehicle" for product development.

The case studies show that certain organizational capabilities are commonly used in the product development process. These capabilities rely on different types of both tangible and intangible structural capital, and can be grouped as:

- The capabilities that are provided by corporate "tools", including software tools that are used for product design and evaluation.
- Data from previous projects. Not only do firms rely on captured knowledge from past projects, but they also need the ability to retrieve that data to shape and validate new designs.
- Corporate processes that aid in product development, allowing firms to manage complexity and simplify repetitive tasks.
- In particular, those corporate processes for managing the needs and requirements of the project, and how these are flowed down to detailed specifications for product subsystems. Given the complexity of most aerospace projects, this ability – to manage the connections between needs, requirements, and specifications – takes on special importance, and can be critical for delivering value to the client.

**Figure 6-2 – Structural Capital capability matrix**

| Ele. No. | Structural Capital (SC) Metric | Capability Matrix | | | | |
|---|---|---|---|---|---|---|
| | | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
| 5 | Tools for product development | • Tools and capabilities are missing to complete critical design tasks<br>• No tool validation, tool customization, or early prototyping to reduce program risk | • Designers have necessary modeling and analysis tools<br>• Limited ability to customize or tailor tools for the project<br>• Each functional group performs work independently | • Translators and tools to share design data across functional groups<br>• Groupware to promote sharing and knowledge transfer<br>• Combination of prototypes and simulations to reduce project risk | • Collaborative design tools to iteratively refine the product between functional groups<br>• Validation of tools to confirm that designs meet performance rqmts.<br>• Customized tools to support manufacturing processes<br>• Financial support for tool creation, modification, and maintenance | • Highly specialized tools for automated design<br>• Customized tools with embedded, codified knowledge from previous projects<br>• Ability to combine analyses and develop systems-level model; use of model to optimize trade space<br>• Tool validation and risk reduction using rapid prototyping & experimentation |
| 6 | Data and knowledge capture | • Minimal requirements for documentation<br>• No emphasis on knowledge capture<br>• Staff complaints about "re-inventing the wheel" | • Knowledge mainly captured in project documentation<br>• No online data management system for project<br>• Limited re-use of knowledge from related projects | • Project data management system to manage design data and documentation<br>• Knowledge re-use and lessons learned from related projects<br>• Previous projects used to validate cost and revenue models<br>• Some attention devoted to creating Intellectual Property (IP) | • IT tools to automate repetitive design tasks<br>• Some documentation of rationales behind design decisions<br>• Functional support for patent/IP creation<br>• Web-accessible search and retrieval of previous project data | • Tools and formal processes for capturing tacit design knowledge<br>• Online documentation that captures design intent, rationales for decisions, and lessons learned<br>• IP management system for licensing and mining IP value |
| 7 | Corporate processes for product development | • Irregular PD processes used from project to project<br>• No formalized process for design changes or changes in procedures | • Corporate processes informally documented<br>• Rigid processes with little to no flexibility in standard procedures<br>• No formalized system for managing changes in engineering drawings | • Standardized mechanisms for defining new processes<br>• Functions are risk adverse to new projects that require changes to standard procedures<br>• Formalized process (ECP, ECR) to manage changes after design freeze | • Cross-functional representation for defining integrated processes<br>• Change management system for modifying established processes<br>• Streamlined approval process, with reduced cost and complexity for implementing changes | • Formalized front-end processes for business case devel. and PD<br>• Established performance metrics for key processes<br>• Process change mechanisms for continual improvement<br>• Flexibility that allows for agile revisions and builds consensus for new approaches |

| Ele. No. | Structural Capital (SC) Metric | Capability Matrix | | | | |
|---|---|---|---|---|---|---|
| | | ***Level 1*** | ***Level 2*** | ***Level 3*** | ***Level 4*** | ***Level 5*** |
| 8 | Requirements management | • "Build-to-print", with no understanding of client needs and rationales behind requirements or specifications | • Requirements document generated early in project<br>• One-time flowdown of specifications to functional groups | • Rqmts/Specs management system that traces specifications to requirements<br>• System for managing interfaces and distribution of specs between functional groups | • Awareness of client needs and their linkage to requirements<br>• Management system enables frequent, iterative changes to spec allocations for design optimization | • Management system allows all requirements and specifications to be traced back to documented client needs |
| 9 | Coordination and alignment of internal stakeholders | • Competing interests between project staff, functional groups, and management<br>• Unclear lines of authority for coordination of efforts | • No alignment of goals between project staff, functional groups, and management<br>• Frequent mismatch between responsibility and authority<br>• Insufficient mgmt. control for resource allocation and coordination of functions | • Use of IPTs for coordinating multidisciplinary efforts<br>• Cross-functional participation in project organization and decisionmaking to promote "buy-in"<br>• Some functional stakeholders may not have clear incentives | • "Goal congruence" between stakeholders, with strong incentives for project success<br>• Project management has needed reporting tools and clear lines of authority & responsibility (RAA) | • Value propositions with clearly defined incentives for internal stakeholders<br>• Project "fit" with corporate strategic plan, synergy between profit centers and corporate strategy |

- And finally, the management's ability to achieve "alignment" of internal stakeholders. The case studies suggest that project success often hinges on the ability to marshal and coordinate corporate resources, including those outside of the project team. To do this, managers need to get "buy-in" from different functional groups, tapping the full benefit of the organization's structural capital.

Figure 6.2 groups these capabilities, and shows how different levels of structural capital can lead to improved performance. As a whole, these case studies provide a number of valuable lessons for managers about using "corporate intelligence" effectively, and how to avoid some common difficulties in mobilizing these knowledge-based resources.

#### *6.3.1. Tools for Product Development*

During product development, firms use a variety of tools – both soft (e.g. design software) and hard (e.g. prototypes and proprietary machinery) – to design and create new products. At a fundamental level, corporate tools are means to extend the capabilities of a firm's human capital, and are a basic element of structural capital. Tools provide the ability to create and innovate, explore trade space, reduce risk, automate repetitive tasks, and transfer knowledge throughout the firm. Conceptually, the dilemma is that "tools" are abstractions that can describe just about anything – however, the case studies show that the most important tools for product development are those that embody proprietary knowledge. The knowledge-based tools of a company embody the wisdom gained from past products, and often are used in combination to create capabilities that no other firm can duplicate.

Used effectively, these tools can generate competitive advantages for a firm by providing unique capabilities, accelerating the design process, and minimizing rework. As the case studies showed, these tools can come in a wide range of forms. In particular, the case studies point to the importance of different categories of tools, and the capabilities that they provide for product development:

- *Design tools.* Design tools are one of the essential elements of structural capital for product development – they are the primary resource that design engineers use to create new products. As seen in the case studies, a number of different design tools were used in the projects, including:
  - Computer-aided design (CAD), modeling, simulation, and analysis software
  - Tools to perform trade-off studies during conceptual and detailed design phases
  - Expert systems and automated design using AI languages

  In particular, firms that customized their design tools were able to exploit their unique capabilities for achieving project goals. The intelligent design software project (Case D) is an obvious example of a specialized design tool that allowed engineers to automate highly repetitive design tasks. Other firms in the studies, such as the experimental aircraft design team (Case B), were able to uniquely combine different design tools to perform systems-level modeling – a capability that allowed the firm to optimize their designs early in the product development process.

- *Collaborative tools.* In addition, engineers and managers in the case studies frequently identified the firm's collaborative tools as an important factor in the project. These tools enabled the design process by fostering a collaborative environment, permitting concurrent engineering, and allowing multiple, rapid design iterations between different functional groups. In addition to corporate "groupware" for data exchange, many firms developed specialized translators, which allowed different functions to rapidly transfer models between their design tools.
- *Rapid prototyping tools.* The case studies also show that firms that could quickly prototype their new products were able to fine-tune their designs and reduce program risk. Projects involving the delivery of large, complex hardware, such as the commercial satellite program (Case G), benefited from the testing of functional prototypes of critical subsystems, allowing engineers to work out "bugs" before production. In the early stages of product development, other firms used prototypes as a tool for conceptual design; the functional demonstrator in the experimental aircraft project (Case B) is one such example.
- *Ability to validate new tools.* Finally, a number of the case studies suggest that tool validation is an important capability that is often overlooked or underemphasized in new product development. Design tools, especially new design software, are only useful if their predictions are valid. With highly novel projects, such as the experimental aircraft case (Case B), tool validation was an important capability to confirm the accuracy of model predictions and assure that performance requirements were being met.

Since these design tools are essential for new product development in the aerospace industry, they often represent major corporate investments. As pointed out by one manager, none of these capabilities come for free, nor are they a one-time cost. Leading-edge firms must be willing to continually invest in tool creation, maintenance, and training to assure that their design teams have the capability to perform complex design tasks, and managers must anticipate future needs to assure that tools are available at the right time.

#### *6.3.2. Data and knowledge capture*

Although "data" is often thought of as only "numbers", it represents the codified knowledge that a company retains from past projects. In this sense, data – in the form of reports, memos, design details, and measurements – is one of the raw materials of structural capital. It is the captured knowledge from past projects that shapes and validates the design effort, the so-called base of "corporate knowledge" which is used for product development. Firms must be able to both capture and re-use knowledge from previous projects, or else suffer from the common complaint of "re-inventing the wheel" on each project that it undertakes.

Just like most firms today, the companies in the case studies have devoted significant resources towards managing their data. Often, the emphasis has been on IT systems and database sharing, with many knowledge management pilot programs focusing on the technology rather than the underlying corporate knowledge. The case studies suggest that high-performing firms not only invest in IT systems, but consider how to capture valuable knowledge from projects and make it accessible for future efforts. Some of the themes from the case studies include:

- *Data for business case development.* Many of the cases relied heavily on data from past projects to develop cost and revenue models for new product development. For example, in the avionics project (Case E) and the foreign military lease (Case F), cost and revenue projections were critical for developing a valid business case and securing "buy-in" from senior management. In these cases, team members went to great extents to collect multiple sources of data and gauge the market potential for their new product, thereby validating their cost and revenue models and reducing risk in their project.
- *Capturing the intent behind design choices.* In a number of the case studies, design team members related that it was difficult to understand the intent behind some of the design choices in previous projects. For projects in their early stages, such as the experimental aircraft project (Case B), engineers studied these earlier choices to better understand and shape their conceptual designs. Often, the project documentation failed to capture the rationales behind those decisions – in effect, important tacit knowledge from past projects was being lost. Some projects, such as the intelligent design software project (Case D), explicitly tried to capture these intents to benefit future designs.
- *Data accessibility.* Besides the intent behind previous design choices, many team members also expressed frustration with the lack of accessibility to previous design data. With each project using a new data management system, previous design data was often buried in an incompatible or inaccessible system. Companies that developed common data management systems, with web accessibility and search capabilities, were able to easily draw upon the lessons learned from past projects. In the military instrumentation project (Case C), designers were able to benefit from a web-accessible knowledge base, with support from the company's knowledge management team.
- *Developing and mining Intellectual Property.* To extract value from data, some firms in the case studies implemented an IP management system for creating, tracking, and "cashing in" on corporate knowledge. Companies devoted different resources towards creating intellectual property, with some firms providing functional support to design teams for patenting new ideas. Often, these firms also actively tried to mine value from existing intellectual property via licensing arrangements to other firms.

Drawing a lesson, the case studies suggest that creating databases is not enough. As discussed in the framework, data are not only perishable, but derive value through their application, not storage. Collecting data in databases is helpful, but knowledge-based assets have worth when they are applied towards value creation for the firm and its clients. Data collection of "knowledge for knowledge's sake" misses the point. Instead, the true value of data lies in its use – namely, in the ability to use past experience to execute on new products.

#### *6.3.3. Process development.*

In addition to tools and data, corporate processes are indispensable components in product design and development. Firms develop processes for strategy formulation, business acquisition, staff allocation, supply chain management, design review, and performance management, just to name a few. Many corporate processes are informal; they emerge over many project cycles, and are often undefined and undocumented "tribal knowledge". The complexity of aerospace projects, however, requires formal process definitions for systematic product development. Like tools and data, processes must also be updated and revised as needed in order to maintain their effectiveness.

In the case studies, a wide range of processes were used for design activities, project management, and manufacturing. The degree to which firms formalized these processes also varied, with some firms developing formalized processes for every step in the product development process. However, the case studies, as a whole, highlight three important capabilities for firms:

- *Developing front-end processes.* Since many of the cases emphasized business case development, formalized front-end processes benefited those firms that were early in their projects. For example, the avionics project (Case E) was launched by a dedicated product development team that used established processes for business case development. The dual-use aircraft concept (Case A) and the foreign military lease (Case F) also used formalized front-end processes that were systematically documented, analyzed, and refined by the design teams. By using these processes, these firms were able to better develop business cases and define project requirements, thereby making a "fuzzy" process more systematic.[70]
- *Process for change management.* Given the magnitude of these projects, most firms benefited by having formalized processes for approving design changes during product development. Although varying in complexity, these processes all provided a formal system for proposing, approving, and incorporating changes in the design, which allowed for better coordination between different functional groups working on the project.
- *Flexibility in corporate processes.* Although processes play a major role in managing complexity, a number of project staff members pointed to "process change" as a troublesome activity in their organization. Once established, processes become rigid – a natural outgrowth of an organization's tendency to resist change. Flexibility, and the ability to adapt processes to changing conditions, is often necessary but difficult to foster, according to these managers. Ironically, process changes in some firms were accomplished by a formal process to implement changes. In the foreign military sales study (Case F), change processes served as a source of continuous process improvement, with empowered team members who collaboratively made process revisions and established metrics to assess the impact of these changes. When successfully implemented, these change processes can promote "kaizen" activities that foster both process improvement and product improvement.

The triad of tools, data, and processes are structural capital assets that, in effect, provide a vehicle for a company's human capital – a means to convert the staff's creativity into highly complex products.

[70] See Wirthlin, "Best Practices in User Needs/Requirements Generation", 2000, http://lean.mit.edu, for more examples of formalized front-end processes.

### *6.3.4. The role of requirements management*

The tools, data, and processes above are the basic structural assets that provide critical capabilities for product development. In addition to these, managers in the case studies frequently pointed to two other structural areas that impacted the project's success. The first of these was the ability to manage the intricate chain of needs, requirements, and specifications for the product and its subsystems. With complex product development projects, a formal process is needed to assure that the final product meets the needs of the client. Before the project begins, the client's needs are embodied or "operationalized" in the definition of project requirements. A top-down process is then employed that refines these requirements and allocates detailed specifications to individual components and subassemblies.

Requirements and specifications must be managed to assure that the end product has the desired functionality and satisfies the client's needs. All of the projects in the case studies used a formal management system for tracking and allocating specifications to different design functions. However, managers and engineers cited two important distinctions with these systems:

- *Dynamic re-allocation of requirements and specifications.* Staff members in many of the projects stressed the value of flexible, dynamic re-allocation of specifications during the design phase. Often, rigid requirements and specifications can become "set in stone", limiting the staff's ability to optimize performance and placing unnecessary constraints on the design. Instead, flexible systems allow lead engineers to explore design space by re-allocating specifications – thereby optimizing performance, minimizing cost, and maximizing value to the client. In the satellite platform project (Case G), a dynamic management system was used for frequent, iterative re-allocations of specifications. This capability allowed for design changes that redistributed the tolerance budget and avoided tightly spec'd and costly subassemblies.
- *Traceability to client needs.* In theory, it should be possible to trace all specifications and requirements back to original client needs. Project complexity, however, can make it difficult to grasp the source or original intent behind detailed specifications. Managers in some of the projects lamented that project requirements often became divorced from client needs, with a loss in appreciation of the original client needs. Management systems that document the origins of specifications can help, by providing rationales for decisions and tracing design requirements back to the end-user needs.

Therefore, a requirement management system is an element of structural capital, albeit at a very detailed level, that provides the capability to assure that products are well aligned with client value.

### *6.3.5. Coordination and alignment of internal stakeholders.*

Keeping track of client needs is important for maintaining a client-oriented focus and "doing the right job". Managers also emphasized that an inward-looking focus is needed to coordinate organizational resources for "doing the job right".

In a number of the case studies, management's ability to align and mobilize resources within the company was a key discriminator between the project's successes and failures. Without support from internal functions – including engineering disciplines, IT, and finance – some projects failed to achieve all of their goals. In other cases, alignment of these internal stakeholders allowed project managers to fully benefit from their corporate resources, effectively applying the firm's structural capital to the project. At a basic level, alignment allows for the coordination of internal staff to create a high-quality end product. More importantly, though, stakeholder alignment is an element of structural capital that provides motivation and clarity – a signal to internal stakeholders to "get with the plan", execute, and excel at their tasks.

A number of the case studies underscore the difficulty of achieving this alignment. This is especially true in large aerospace firms, where aligning functions and divisions can be complicated by the complex nature of the organization's structure. With a decentralized organizational structure, corporate policies often require each function to be evaluated as an independent profit center, accountable for its own budget. In this environment, the case studies suggest that managers need to consider the following steps to promote internal alignment:

- *Creating common goals between functions.* First, managers need to consider whether there is "goal congruence" between the internal stakeholders in the project. In the intelligent design software project (Case D), the project's goals clearly threatened the status quo of other functional groups, making goal congruence almost impossible. In other cases, such as the avionics project (Case E), there simply was no clear incentive for alignment with the program goals. For individual functions and the managers of independent product platforms, the rewards for getting behind the project did not justify the risks.
  During the formative stage, managers need to consider how goal congruence can be fostered within the firm. As a start, program managers should consider how the project fits with overall corporate strategy, and how to define and articulate this fit with the managers of supporting functions. First, managers should enlist the support of senior management to marshal forces and align goals within the organization. In risk-laden development programs, such as the experimental aircraft project (Case B), managers need to craft a "value proposition" that identifies why supporting functional managers – especially those with indirect or loose ties to the project – should have an interest in the success of the project. Clearly defined incentives, such as the contract fee incentives in the military instrumentation project (Case C), also can promote goal congruence between internal functions.
- *Maintaining "buy-in".* Programs such as the satellite program (Case G) benefited from cross-functional participation in the early stages of project planning, helping to sustain "buy-in" later in the project. The use of integrated project teams (IPTs) with managerial representatives from all impacted functions also helped assure that functional managers stayed involved and committed to the project goals.
- *Clear lines of authority and responsibility.* Programs with complex organizational structure also benefit from clear lines of responsibility, authority, and accountability (RAA). Given that aerospace projects are not just interdisciplinary but are often decentralized and multi-divisional, project managers profit from clear reporting within all functions and teams.

Alignment, therefore, enhances a company's ability to "do the job right", making sure that corporate resources are committed towards a common goal. In order to effectively use their company's structural capital, the case studies show that managers need to consider internal alignment when planning and executing their projects.

Since structural capital is the form of intellectual capital most clearly owned and controlled by the firm, it intimates that it is the most easily managed as well. In reality, the cases suggest that managers face a difficult task when trying to manage and marshal the power of their structural capital. Although corporate tools, databases, and processes are powerful aspects of structural capital, managers must be able to align and coordinate their organization's stakeholders in order to tap their full benefit.

### *6.4. Relational capital*

Of the types of intellectual capital, relational capital is perhaps the most difficult for firms to manage successfully. Relational capital not only takes the longest time to develop, but it is often difficult to "cash in" or convert into tangible value for a project manager. Strategically, the cost/benefit of long-term investments in relational capital is also hard to justify, since its connection to profitability is almost impossible to quantify. Given these difficulties, many managers do not consider building the firm's relational capital as a high priority in their work. Nonetheless, the case studies clearly show that firms succeed by leveraging the value of relationships developed over time, and they can fail if these critical relationships are absent.

Strong relationships allow for capabilities – for example, an understanding of client value, an awareness of the competitive landscape, or access to suppliers and manufacturing capabilities – that can make or break a project. In retrospect, every project in the case study was dramatically influenced by the quality of its relational assets. The cases affirm that managers must begin early, sometimes well before project conceptualization, to develop relational capital between the firm, its clients, and key suppliers.

How can managers get a handle on their relational capital? The cases suggest that managers use their relational capital to provide capabilities in five key areas, where external ties and strong relationships outside of the firm were critical resources for project success:

- The capability of the firm to understand their client (i.e. the client's definition of value), combined with the firm's ability to align its resources towards delivering that value
- The strength of the firm's relationship with the client, as indicated by the degree of client involvement in the planning and operations of the project
- The benefits derived from the "brand" or reputation of the firm, as driven by past performance and the track record of the firm
- The quality of a firm's relationships with partners and the supply chain, providing access to key external capabilities for the project
- An understanding of the regulatory environment, which is often an essential component of aerospace projects requiring government approval, certification, or export licenses.

The capability matrix in Figure 6.3 summarizes these activities for enabling project success, and provides managers with a template for improving the long-term stock of relational capital. The emphasis here is not on an individual's skills (an aspect of human capital), but rather on the lasting relationships that occur between firms, their clients, and their suppliers. By considering how organizations build relationships, the concept of relational capital can help managers identify how to craft winning propositions that bring value to both the firm and its client.

### *6.4.1. Alignment with client value*

The first commandment of relational capital is "know thy client". The case studies suggest that understanding the client – knowing what they want in a product and their definition of value – is the first critical capability that relational capital can provide. At the simplest level, value is created for the client by executing the tasks as defined by the contract, including delivery of the final product. However, client value is more than a list of deliverables. Real value is created by first understanding and identifying client needs, and then providing capabilities and solutions that meet those needs, at the right time, at the right price.[71] In product development projects, this is a dynamic, iterative task where the definition of client value is frequently revisited and revised during the course of the project.

In addition to this understanding of value, the cases show that organizations must promote a client-oriented focus to assure that the end product meets the client's goals. This requires an "alignment" with client value, which is analogous to the alignment of structural capital. Whereas structural capital is needed to "do the job right", the alignment of relational capital is needed to "do the right job". The case studies show that successful managers consider how to align their projects with client value, so that processes and resources in an organization are applied effectively to create value for the customer. Often, this involved taking implicit aspects of the value proposition, and making them into explicit activities that promote alignment with client value. These include:

- *Linking deliverables to client value.* End products – especially those driven by client "pull", as in the commercial avionics project (Case E) – are clearly providing value and satisfying a client need. In other cases, managers considered how other steps in the project, such as intermediate deliverables, can create value for the client. The managers of the experimental aircraft case study (Case B), for example, proposed a proof-of-concept demonstrator not only to reduce program risk, but to allow the client to establish program legitimacy with its sponsoring agencies and secure continued funding.
  This exercise – of explicitly framing each step in new product development in terms of client value – can help managers identify the win-win aspects of a project. The underlying philosophy here is a fundamental lean principle: if tasks do not contribute to value creation,

[71] More details about the value creation framework – value identification, the creation of a value proposition, and value delivery to all stakeholders – is developed in Earll Murman, et al., "Lean Enterprise Value", 2002.

**Figure 6-3 – Relational Capital capability matrix**

| Ele. No. | Relational Capital (RC) Metric | Capability Matrix | | | | |
|---|---|---|---|---|---|---|
| | | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
| 10 | Alignment with client value | • Mismatch between client needs and final product<br>• Deliverable does not create value for client | • Final deliverables of contract as means of delivering value<br>• Client "pull" defines the new features of the product | • Intermediate deliverables formally linked to client value<br>• Incentives or payments linked to intermediate milestones | • Formal process to identify value (value proposition) for the client<br>• Life cycle costs identified and included in value proposition<br>• Client value used as metric in design trade studies and stage gates | • Strategic alignment of client value with corporate (shareholder) value<br>• Win-win mutual arrangements (such as incentives, royalties, or equity sharing) codified in client-prime contract |
| 11 | Client involvement | • "Build to print" project with limited client involvement | • Client provides rqmts. document<br>• Client provides feedback at design reviews | • Client involved in weekly/monthly design meetings<br>• Client has intermediate input into design process | • Early client involvement in downselection of design concepts<br>• Frequent (almost daily) client involvement in design process | • Client staff co-located with design team<br>• Client participation and "buy-in" of iterative design changes (client as member of the design team) |
| 12 | Collaboration with suppliers and partners | • No formal partnering agreements<br>• Cost as only criteria in supplier selection | • Supplier input during RFQ process<br>• No supplier involvement during early design phase | • Supplier involvement in design process and reviews<br>• Informal partnerships to manage interfaces and assure component compatibility | • Formal partnering agreement with key suppliers<br>• Strategic alliances for needed capabilities<br>• Some co-location of staff during critical phases of project<br>• Web-based tools for collaboration, concurrent design, and supply chain management | • Contractual mechanism to align partner goals with needs of prime contractor and client<br>• Procedures to streamline knowledge transfer and protect proprietary knowledge<br>• Co-location in collaborative design environment during PD phase |
| 13 | Relationships with regulatory agencies | • No regulatory considerations during product development | • Product requires certification or export licensing<br>• Identification of all regulatory stakeholders (e.g. FAA, Customs, State Dept., DoD)<br>• No early relationships established with agency personnel | • Designate engineering representative(s) with responsibility for regulatory matters<br>• Work with agencies to identify requirements for certification and technology transfer<br>• Establish peer-to-peer working relationships with agencies | • Early involvement of regulatory stakeholders to identify issues<br>• Allocate appropriate scheduling contingencies for regulatory delays | • Established track record of dealings with agencies<br>• Strong working relationships with local and national regulatory offices<br>• Lobbying to influence and change regulatory process |

then they're waste. Linking these tasks to client value can therefore boost the relational capital in the project.

- *Incentives.* Formalized incentives help an organization maintain a client-oriented focus by emphasizing the goals of critical importance to the client. For example, tying award payments to early delivery on time-critical projects, or linking progress payments to intermediate deliverables, are effective tools that emphasize the continual creation of value for the client.
- *Innovative contracts.* A number of the successful case studies involved unique, win-win contractual arrangements that were atypical for aerospace projects. For example, the satellite platform developers (Case G) were required to invest in the limited partnership, thereby aligning firm performance with the client's interests. In the military instrumentation project (Case C), client value was created by teaming two organizations and cross-pollinating their technologies, thereby developing multiple sources for advanced technologies. Contract award payments were even linked to the degree of knowledge sharing and cooperation between the firms. Novel contractual mechanisms, including innovative leases, royalties, and equity sharing, can help assure that client value remains the central goal of the project.

Simply put, alignment with client value is just part of an overarching lean practice: to maintain focus on the customer and their needs. The case studies show that managers need to consider how well the resources of the firm are aligned to deliver this value, making sure that the organization maintains a client-oriented focus.

### *6.4.2. Client involvement.*

Client involvement in both planning and executing the project is one way to assure that the final product meets the client's needs. Managers, however, often wrestle with this question: how much client involvement is helpful, and can it be disruptive?

The projects in case studies showed different degrees of client involvement, with novelty as the discriminating factor. Projects with routine activities, such as fabricating parts that are "build to print," do not require a high degree of client involvement. However, most product development, by its very nature, involves novel activities for a firm and a high degree of uncertainty, including identifying requirements and understanding what the customer really wants. The cases show that the need for client involvement increases with the novelty of the task, and that frequent, iterative interactions were needed to allow individuals with different organizational frames to understand each other and work together.

Two distinctions can be made from the case studies:

- *Early client involvement.* Projects in the front end of product development – when concepts are still formative and business cases are still being developed – benefited from frequent client involvement. In the military aircraft lease (Case F), early working groups with the client were needed to collaboratively develop a business plan for the project. Here again, the project profited from the early involvement of a "champion" client, who helped identify a win-win arrangement for the firms. As a project takes shape, this frequent client input also assures that the tasks and intermediate deliverables will be focused on providing client value.

- *Co-location and involvement in design process.* The military aircraft project also benefited from client staff that was co-located with the project team during the design phase. Co-location with the client was helpful in understanding the requirements for aircraft certification overseas – a task that was unclear, yet critical for project success. With novel projects, client involvement during the design phase is crucial for translating across both organizational and cultural boundaries, assuring that the design meets all customer requirements. In highly innovative projects, such as the experimental aircraft program (Case B), intimate client involvement allows the design process to be dynamic, highly interactive, and focused on delivering client value.

In these novel projects, client involvement was much more of a benefit than a hindrance. Frequent collaborations promoted the sharing of important, context-specific knowledge between the client and the design team, and allowed the firm to have a better understanding of client value.

The case studies also suggest that involvement not only allows the team to "do the right job", but has other beneficial side products. Inclusiveness and frequent communication enables the growth of trust between client and firm, helping to create an effective relationship that is a core principle of the lean enterprise model. Finally, client involvement promotes "buy-in": by participating in the development and downselection of concepts, the client indirectly shares in the accountability for decisions made in the product development process.

#### *6.4.3. Past performance*

Another important aspect of relational capital is the reputation of a firm, and how it is perceived by both existing and potential clients. Outside of the aerospace industry, companies pay dearly to develop a reputation and brand awareness for their consumer products. In aerospace, this reputation is built on past performance and trust, and takes years to develop or rebuild. It's the most difficult aspect of relational capital to create, and the most important as well.

The case studies, unfortunately, are snapshots in time, and do not thoroughly explore how firms develop and enhance their reputation over time. It is clear, however, that firms with a strong track record of past performance were able to leverage it to create new business opportunities. The best examples of this are the commercial derivative of a military aircraft (Case A) and the foreign military lease (Case F). In both of these cases, the military client was willing to enter into novel and potentially risky business arrangements, based on the firms' history of successful execution on past projects. Trust was built long before these projects started, built on a bedrock of past performance. Managers, whether they like it or not, must rely on their company's track record to build credibility and instill confidence in the promises made with their clients.

The importance of trust and reputation, although clearly part of relational capital, is beyond the scope of this research. The case studies, with their project-oriented scope, nonetheless suggest that managers need to be mindful of the long-term task of building reputation, how it affects their ability to win contracts, and its central role as an asset in its relational capital stocks.

### *6.4.4. Collaboration with suppliers and partners.*

To deliver client value, a company must also collaborate and coordinate with firms that can provide needed capabilities for the project. Relational capital, therefore, includes the quality of the company's relationships with its suppliers – firms that supply critical components, subassemblies, and services that are "shopped out" during the contact. Also included are partnerships, where firms with different core competencies combine their capabilities to deliver an integrated solution to the customer.

Drawing some parallels, relational capital with suppliers and partners has similar traits to the relational capital with a firm's client base. Just like client capital, successful collaborations with suppliers are built upon a base of strong performance, prior experiences, and mutual trust – attributes which develop slowly and are established over time. And just as strong relationships enable an understanding of client value, strong relationships can provide an understanding of a supplier's cost and revenue structure, providing valuable knowledge about how to craft winning collaborations with other firms.

As with client involvement, the case studies show that novel projects can greatly benefit from the early involvement of key suppliers and partners. Based on the case studies, the capability matrix identifies activities and resources that promote cooperation between suppliers and partners, enhancing the knowledge transfer between firms. These enablers include:

- *Partnering and strategic alliances.* Partnerships and alliances provide access to mission-critical resources that a firm may be missing. Product development projects in the case studies not only involved alliances and partnerships, but included contractual incentives and unique teaming arrangements. Win-win contractual arrangements, whether they involve profit sharing, equity sharing, or royalties, helped motivate partners to strive for mutually defined, mutually beneficial goals. In one case, the military instrumentation project (Case C), the contract was structured to foster partnering with the firm's chief competitor, with award incentives tied to cooperative performance. In the satellite project (Case G), the partnering firms all invested in the new joint venture, so that the firms had a direct financial interest in the success of the project. Instead of a self-serving focus, innovative arrangements like these can help motivate these firms, encourage commitment of "high performers" and key resources to the project, and align subcontractors towards delivering value to the end user.
- *Supply chain integration.* Today, project managers realize that their task is more difficult than simply managing their supply chain; it is necessary to integrate the supply chain into the enterprise to deliver the right parts on-time. Supply chain integration is a critical capability that a firm can use to gain competitive advantages. If done properly, integration enables coordination of efforts and the fast diffusion of information between firms to maximize value delivery to the client. Done improperly, it can lead to schedule delays, interface conflicts, rework, and waste.

- *Collaborative tools.* Projects with a high degree of partnering and supply chain integration, such as the military instrumentation program (Case C), utilized a project web portal for team members and suppliers to exchange design data, coordinate efforts, and track project status. Given today's information technology, collaboration tools, and the growth of web-based data management systems, companies can promote knowledge sharing to a greater degree than ever before.
- *Co-location during design phase.* However, interviewees in the case studies confirmed that IT tools do not replace the need for face-to-face interaction, especially during new product development. Just as client co-location can help foster a strong client-firm relationship, co-location of these design teams can play a big role in successful partnerships. In the satellite project (Case G), engineering teams were first co-located during the early design phase, promoting collaboration and camaraderie between the partnered firms. Later, teams were also co-located during hardware integration. Besides fostering knowledge exchange, these co-located activities represent an important signal – that firms are willing to commit their valuable human resources to the joint effort.

For the prime contractor, these alliances and supply chains are important for getting critical resources and needed capabilities for the project. The keys to securing these external resources are the firm's relationships – past collaborations, open communication, and a degree of trust – that develops over long periods of time. This caliber of relational capital is not created overnight. Since firms typically do not have all necessary skills and capabilities in-house, managers need to consider the slow clockspeed for developing relational capital when planning upcoming projects.

### *6.4.5. Relationships with regulatory agencies.*

Finally, when assessing the health of their relational capital, managers should not forget to consider relationships with regulatory and oversight agencies. For the aerospace industry, these typically include the FAA, EPA, Customs, the State Department, and Congressional subcommittees with oversight authority. Regulatory hurdles are not unique to the aerospace industry, but their role is often a pivotal consideration when developing business cases and identifying potential customers.

Once a project is started, managers also need a detailed understanding of regulatory requirements to avoid delays and assure timely delivery of the product. By design, regulatory requirements are often vague and subject to a wide range of interpretations. This puts a special burden on companies to identify regulatory stakeholders early, and establish working relationships with peers in the agency staff. Again, this is another aspect of relational capital that is developed slowly, based on prior experiences, and requiring multiple interactions over the product development cycle.

From the case studies involving regulatory oversight, three main lessons can be learned:

- *Early involvement of regulatory stakeholders.* The case studies emphasize the value of early involvement by regulatory stakeholders to clarify requirements, address issues, and streamline the regulatory process. Early involvement is critical, as virtually every manager lamented that unforeseen complications arose during the course of the product development. In some cases, such as the foreign military lease (Case F), regulatory input was sought early during the business case development, which indicated that lobbying and proactive political action was needed to obtain special exemptions or to pass legislation that modified regulations. In the avionics project (Case E), however, managers may have underestimated the regulatory complexity of FAA certification, delaying the project in its final stages. Given the level of frustration expressed by the case study managers, the need for early development of regulatory relational capital cannot be overemphasized.

- *Allocated sufficient schedule for regulatory delays.* Even with advanced planning, many managers complained that resolving regulatory issues, as well as completing the certification process, took longer than expected. Despite foresight and best efforts, the case studies show that managers should expect delays, and budget accordingly.
- *Develop peer-to-peer relationships.* Finally, project managers from the case studies identified peer-to-peer relationships as the key element in establishing effective working relationships with regulatory agencies. In a number of cases, designated engineering representatives with an established track record in regulatory matters were assigned for the course of the project, and worked with their regulatory counterpart to identify requirements for certification, technology transfer, and export licensing. In cases such as the foreign lease (Case F), these peer-to-peer relationships were invaluable; when confronted with regulations that were subject to interpretation, many disputes were resolved at this personal, peer-to-peer level.

Given the complexity of aerospace projects that require government approval, certification, or export licenses, it is essential that project managers possess a solid understanding of the regulatory environment. To effectively navigate this maze, important relationships must also be in place to identify issues and resolve disputes as early in the process as possible. As the third category of intellectual capital, it is clear from the case studies that relational capital not only complements the firm's human and structural capital, but may be the most important asset to possess for complex aerospace projects.

### *6.5. The lens of intellectual capital*

As a whole, the case studies exemplify how aerospace firms can apply their intellectual capital – their collection of knowledge-based assets – towards creating complex products and services. Based on the common traits from the seven projects, we can see that there are clear patterns about how these firms used their human capital, structural capital, and relational capital. These assets, taken individually, don't provide crucial insights about knowledge and its role in product development. They are often intangible, unwieldy, or too conceptual in nature to tell us much. Surely, we can say that with intellectual capital, more is better. But how do firms effectively use the intellectual capital that it has, as well as identify and procure the intellectual capital that it needs?

The instructional value of the case studies can be found not in individual assets, but in the big picture about intellectual capital. First, the concept of intellectual capital can be thought of as a "lens" to identify the underlying assets that a firm possesses. By categorizing these assets as human, structural, and relational capital, we can see patterns emerging about the similarities and differences in the case studies. These patterns allow two types of comparative analysis: we can see how each different type of intellectual capital contributes to creating essential and unique capabilities for product development. We can also see the similarities and differences between the case studies, identifying how some projects were enabled by their assets, while others suffered from missing assets and capabilities.

How can these results help managers with their own projects? In reality, each manager is faced with a different set of circumstances. Are the above results case-specific? Since managers have different requirements and different assets to apply towards their project, do the findings from a particular case study have any relevance?

The comparisons from the case studies show that, rather than focusing on specific knowledge-based assets, the common threads are the capabilities that intellectual capital provides. Capabilities – such as the ability to manage and promote a collaborative design effort, the ability to align internal stakeholders, or to understand client value – are more important to a project manager than the underlying assets. Managers need results, not concepts. Practitioners need to know how to use intellectual capital in an applied sense, i.e. how to apply it towards achieving project goals. The case studies show that intellectual capital can be used as a lens to identify the common capabilities, derived from knowledge-based assets, which lead to project success.

The result is that managers can use the above capability matrices as a self-assessment tool. First, the matrices can be used to help identify the knowledge-based assets in the firm, serving as a means to assess the health of their intellectual capital base. Secondly, the matrices allow managers to assess whether they have all of the capabilities needed for product development. Using the matrices as a starting point, managers can go through the exercise of identifying specific resources and activities that are needed for their project, and where key capabilities are missing. The next chapter provides some guidance on this capability gauging, including details on using the matrices to self-assess, plan resource allocation, and consider long-term strategic needs as well. Although no tool is perfect, it is hoped that these capability matrices will not only will promote an awareness of intellectual capital, but help managers use their knowledge-based assets for today's operations and tomorrow's opportunities.

# 7. Discussion

## *7.1. Measuring and managing intellectual capital*

If intellectual capital is the critical resource for the new business paradigm, then why aren't firms doing more to develop it? The truth is that firms are not only aware of the importance of their knowledge-based assets, but they are doing something about it. Efforts to boost corporate America's knowledge stocks still continue, although not always under the banner of "knowledge management" or "intellectual capital". With the current business downturn, the popularity of these movements has clearly faded in the last few years. Firms still recognize the value of their corporate knowledge, and the importance in keeping it up-to-date. The failure of the knowledge movement, however, has less to do with the economic downturn; its fundamental problem is the difficulty of working with assets that, for the most part, are intangible.

From the analysis of the case studies, it is clear that intangible corporate assets are important resources that are leveraged to achieve program goals and create value. Like all intangibles, these assets are hard to pin down, difficult to identify, and almost impossible to value. Although project managers in the case studies identified critical assets such as staff experience, expert software for rapid prototyping, or collaborative relationships with clients, these assets don't appear on the corporate balance sheets, and are often difficult to identify or formalize. Clearly, a better understanding of intellectual capital can help. By categorizing these critical assets as human capital, structural capital, and relational capital, we can begin to identify some of the necessary components for project success, organize them in a useful fashion for managers to use, and begin to define metrics that measure and track them over time. Even though these categories are helpful, however, something more is needed to turn the concept of intellectual capital into a useful tool.

This research provides a number of tools that, hopefully, practitioners will use to manage their intellectual capital. First, the conceptual framework provides insights into the dynamic nature of knowledge-based assets in the firm – insights that go well beyond the static categories of human, structural, and relational capital. Although previous research had defined what intellectual capital is, there is a distinct need to extend this definition and explain how intellectual capital can be utilized in the workplace. By developing a mental model of how knowledge is created and transformed, the framework begins to help managers understand the dynamic aspects of the knowledge in their firms. It explains the central role of human capital, the importance of organizational learning, and, most importantly, intellectual capital's connection to value creation. As a tool, the framework provides a deeper level of understanding to guide our actions.

In addition, the capability matrices are a second set of concrete tools for measuring and managing intellectual capital. Based on insights from aerospace development projects, they can serve as a rudimentary system for measuring and managing a firm's knowledge-based assets. The matrices – framed in the concepts of human, structural, and relational capital – provide the all-important link between the theories of the framework and real-world application. Project managers can use the matrices to self-assess their intellectual capital base, and apply the results to allocate resources, guide procurement efforts, and identify areas for strategic development.

Although the research so far has presented these tools, what's missing are explicit instructions for how to use them. In this chapter, we will explore how these tools can be used by researchers and managers, as well as their implications for the aerospace industry as a whole. The chapter begins with a little context – after reviewing the current state of intellectual capital movement, we discuss the significance of this research:

- Its implication for further research and data collection on intellectual capital
- The research's implication for public policy, with recommendations for both financial and regulatory changes
- Most importantly, its implication for managers of product development projects. We offer some guidelines about how to use the framework and capability matrices to improve both today's operations and tomorrow's opportunities.

### *7.2. The measurement dilemma in today's economy*

Unfortunately, the intellectual capital movement to date has had only a modest impact on the way firms do business. With the economic downturn, many companies have scaled back their pilot programs for knowledge management, and have eliminated newly-developed intellectual capital functions and their directors[72]. No one disputes that these knowledge assets play an important role – but without tangible fruits from these efforts, most companies find it hard to justify the cost of these programs.

So, if intellectual capital is important, then how has the movement failed to live up to expectations? It's easy to dismiss intellectual capital as another management fad, a "flash in the pan" whose time has come and gone. Intuitively, though, we sense that there is something profoundly important about utilizing and managing our knowledge-based assets – it's just that we don't have the understanding or tools to guide us in the process. Like many strategic plans with lofty goals, intellectual capital's failure has been in execution, not in the legitimacy of the concept.

The failure of the intellectual capital movement can, in part, be blamed on the emphasis placed on measurement. The mantra of the aerospace industry – that "what isn't measured, isn't managed" – has, perhaps, mistakenly emphasized the quantitative nature of intellectual capital management, and financial valuation of these stocks in particular. When the movement began, most practitioners immediately grasped the importance of corporate knowledge in today's economy, and launched into an effort to measure the intellectual material – tangible or intangible – that lies within their firm's control.

[72] See, for example, the Wall Street Journal article by Pringle, David, "Learning Gurus Adapt to Escape Corporate Axes", Jan. 7, 2003, Marketplace, p.B1-B4.

Without a solid framework for understanding intellectual capital and its role in value creation, many of these efforts went astray. As discussed in the literature review, much of the measurement effort has attempted to quantify or assign dollar amounts to these intellectual assets; surely, it seems logical to "take stock" of any critical resources before launching into any management effort. Undeniably, the measurement effort was also fueled by a desire to "rank" and compare our intellectual assets with our competitor. Besides being a natural instinct, strategic planners want these measurements to help gauge the competitive landscape, especially given the large investments needed for new product development. In and of itself, there is clearly nothing wrong with trying to measure a company's stock of knowledge.

With knowledge-based assets, however, financial-based metrics just don't make sense. Many managers quickly realized that financial valuation was not the key to understanding their firm's critical assets, and naturally gravitated towards a more "balanced" valuation approach. Kaplan and Norton's balanced scorecard[73] was the most widely adopted alternative. The scorecard helps managers by providing a "recipe" for developing non-financial metrics in categories such as customer perspective, internal firm goals, and growth opportunities. Using self-developed metrics in these areas, many firms were able to break away from a mindset that was limited to conventional financial metrics. Yet, something is missing from the balanced scorecard approach. Although it addresses some measurement shortcomings, it doesn't really address the heart of the problem: the role of knowledge in the firm.

Although the balanced scorecard method includes aspects of human, structural, and relational capital, it doesn't provide a framework for understanding how that knowledge is created, transferred, and transformed in the firm. It provides a recipe for managers to follow, but it doesn't provide some important insights. Key questions remain about "why is this important", "how does this add value", or "what lasting capabilities should we be building". What's missing are insights about the different types of knowledge in the firm, the capabilities they provide, and how these how knowledge-based assets are connected to value creation.

In this sense, measurement alone is not enlightening unless there is a framework to understand what's being measured. Quantifying stocks doesn't necessarily help managers with their day-to-day tasks. Nor does "taking stock" necessarily help strategic planners either. Stocks alone are not useful unless they are part of a larger understanding of the dynamic role of intellectual capital in the firm. This is where the different aspects of this research come together – where the proverbial rubber meets the road. Managers need to not only know what stocks to measure, but also how these stocks contribute to value creation – both short-term and long-term – for their company.

[73] Kaplan, Robert S. and Norton, David P., "The Balanced Scorecard", *Harvard Business Review*, Jan-Feb. 1992, pp.71-79.

### *7.3. Intellectual capital and value creation*

This research on intellectual capital, therefore, offers two distinct advantages to managers. First, it provides a framework – a "mental model" – for understanding the types of knowledge in the firm and how they are interrelated. Second, intellectual capital rests on a fundamental tenet of lean philosophy: the emphasis on creating value for the firm and its clients. The conceptual framework provides a way of thinking about knowledge-based assets; given their intangible nature, it's not surprising that many managers have trouble grasping the extent and import of their firm's intellectual capital. The constructs of human, structural, and relational capital help organize these intangible assets into manageable categories. Using the framework as a lens, practitioners can therefore begin to take stock of these knowledge-based assets.

The connection to value, however, is how these stocks are used. Rather than simply stopping after the measurement task, we need to realize that intellectual assets are a means to an end – the all-important connection to value. What insight is gained by measuring, say, the number of staff members with PhD degrees in the firm? It may be an indicator, but how is it useful to managers? Measurement alone misses the point. Intellectual assets don't have value in and of themselves, but are resources that provide a firm with unique capabilities – capabilities that allow a firm to provide products and services that other firms cannot. Capability gauging, combined with an understanding of the firm's intellectual assets, is the all-important second step for understanding intellectual capital's connection to value creation. Combined with the framework, the capability matrices from the case study can then be used as a tool for looking at how each firm's human capital, structural capital, and relational capital contribute to creating value.

### *7.4. Intellectual capital, synergies, and competitive advantage*

Based on the case studies, the firms that were most successful in creating value used all aspects of intellectual capital – human, structural, and relational – to achieve internal goals and satisfy client needs. Managers of the foreign military lease project, for example, relied on established organizational processes, staff members with military experience, and key relationships with their regulatory counterparts to achieve program goals. The satellite program is another example where relational assets were as critical, if not important, than the firm's structural capital. Other projects, unfortunately, could not rely on the same well-rounded intellectual capital base. The capabilities needed for success, it seems, requires a balanced portfolio of intellectual capital. Rarely is a capability derived from a single type of intellectual capital: it takes multiple "pieces of the puzzle" to assemble the necessary components for developing new products and services. Balance, it seems, is not only a good thing for measuring intellectual capital; a balanced portfolio of intellectual assets is needed for managing successful product development efforts.

As suggested in the conceptual framework, the case studies seem to support the conclusion that intellectual capital is synergistic. Projects, such as the experimental aircraft, that combine existing modeling tools with new technologies, consultant input, and a dedicated development team can create capabilities where none existed before. In general, most observers would probably agree that the whole of a firm's intellectual capital is greater than the sum of its parts.

Experience with project teams tells us that individuals with different skills combine to create unique design capabilities, and that a firm's structural and relational capital is complementary to its human capital. The strongest proofs of synergy, however, are the failures in cases where an aspect of intellectual capital was missing. The case studies clearly showed that many strongly equipped projects – for example, project teams rich in human and structural capital – were derailed by a lack of relational capital, or other missing assets and capabilities.

Awareness of this critical interdependence is not new, nor ground-shaking. Many organizational theorists have investigated the interplay between human capital and the organization, emphasizing that human capital research must be embedded in an understanding of the firm's organizational processes and organizational culture.[74] Managers also know that it's all interrelated, but which synergistic assets are important and deserve their attention? The challenge, then, is to recognize the complementary assets when managing the firm's portfolio of intellectual capital. Managers need to understand whether they truly have the right "mix" of human, structural, and relational capital to execute new projects.

To identify the critical, complementary assets, it's helpful to consider which combinations clearly result in a competitive advantage for the firm. The key is to identify the combination of assets that provide unique capabilities, which other firms cannot replicate. As discussed in the literature review, this resource-based view of the firm – where difficult-to-imitate resources lead to competitive advantage and differentiated performance – holds especially true for intellectual capital. If aspects of intellectual capital truly work in concert, then competitors would face a substantial barrier in trying to replicate a broad combination of human, structural, and relational assets. This is especially true since intangible assets, by their nature, are often difficult to procure or cannot be quickly replicated. By finding these combinations that provide unique capabilities, managers can leverage their intellectual capital to maximize value for their projects.

This realization is often missing from today's discussions about the role of knowledge in firms. Efforts to amass knowledge-based resources – knowledge for knowledge's sake, so to speak – fail to recognize the importance of synergies and non-replicability. This is where the true value lies. This mistaken assumption about knowledge-based assets occurs quite frequently. For example, in a recent issue of the Harvard Business Review, Nicholas Carr[75] points out that chief executives falsely assume that investments in information technology (IT) automatically result in differentiated performance and competitive advantage in their industry. Managers fail to realize that knowledge-based assets have premium value when they are non-replicable, since they can't easily be bought. If competitors have the same access to these resources (i.e., they can buy the same knowledge), then it's a commodity input, not a differentiating capability. Although IT systems may be a necessary asset in today's information-rich business world, it's not sufficient for differentiated performance.

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[74] For a recent summary of research on these interrelationships, see Blair, M.M. and Kochan, T.A., *The New Relationship: Human Capital in the American Corporation*, Brookings, 2001, p.22.

[75] Carr, Nicholas G., "IT Doesn't Matter", *Harvard Business Review*, May2003, Vol. 81 Issue 5, p41.

However, Carr fails to realize the bigger consideration: the synergistic value of knowledge-based resources. Individual assets, such as IT systems, have middling value; but combinations of assets, however, create unique capabilities that maximize the value of a firm's knowledge-based assets. Alone, IT is just a commodity, but combined with corporate processes and proprietary knowledge, it can create a differentiating capability. Therefore, it's not the IT system, but what you do with it. Once again, knowledge-based assets derive their value from the capabilities that they provide, and the case studies confirm that a balanced portfolio creates synergies that can lead to project success.

### *7.5. The invisible contributions of intellectual capital*

Although these synergies generate additional value, they can be confounding for researchers investigating intellectual capital's role in firm performance. Synergies can make it difficult to gauge how each type of intellectual capital individually contributes to value creation.

This difficulty is nowhere more obvious than with human capital. At first glance, we would expect firms with superior human capital to perform better than their competitors. As the preeminent form of intellectual capital, we would expect the quality of a firm's staff to be the greatest determinant of improved firm performance. And we would also expect that investments in human capital, such as staff training, would make a significant impact on corporate performance.

The truth is that there is a lack of definitive research that measures human capital's contribution to corporate success. Without strong data that establishes causal connections, we can only assert that human capital is the "invisible" engine that drives product development. Given the interconnected nature of intellectual capital, it is also difficult to craft a research methodology that isolates human capital's contribution. Certainly, a wealth of studies point to human capital's importance in product development. A recent LeanTEC study, for example, concluded that staffing levels and the over-extension of top performers significantly influenced the success of new technology projects in military aerospace programs.[76] However, organizational research does not take place in a test tube, and it is often difficult to isolate and quantify the contribution of human capital assets to program success.

In hindsight, the research in this report suffers from a similar defect. In all of the case studies in this research, program managers cited the high quality of the project team as a critical enabler for program success. No quantitative data was collected to independently assess the quality of the workforce, and given that all managers claimed that they were staffed with top performers, the research may have suffered from a selection bias. Without the ability to discriminate between poorly-staffed and highly-staffed project teams, the research does not definitively establish a causal connection between human capital and project success. The question needs to be asked:

[76] For more details, see "Lean Transition of Emerging Industrial Capability", AF Research Lab Cooperative Agreement F33615-97-2-5153, http://www.centralstate.edu/LeanTEC, 2001.

did human capital really make a difference in the cases? We are left to speculate that, like IT systems, that strong human capital is a necessary but not sufficient condition for project success. In the case studies, managers may not have even considered initiating the project unless they had a minimal level of staffing and experience to support the effort. Only after this necessary condition is satisfied, product development projects can then proceed. The design of this research, however, offers no conclusive data that isolates human capital's contribution and confirms its importance for project success.

Researchers in the area of intellectual capital are all hampered by this lack of data. To be able to discern trends and patterns with intellectual capital investments, we would need to be able to compare resources, capabilities, and investment levels with metrics for project success across a large sample of cases. Unfortunately, this data does not exist. Internally, firms do not often attempt to measure the relative effectiveness of their investments in staff training, for example, in relational capital, or in other intangible assets. Externally, very little aggregate data is available to discover industry-wide trends, as businesses have no incentives to publish non-financial reporting data on intangibles within their firm.

### *7.6. Data collection and public policy implications*

Researchers and practitioners are therefore faced with a paradox: despite their gut feeling that intellectual capital is today's all-important asset, there is little data to support or gauge its return-on-investment. We can throw in the towel, relegating intellectual capital to the status of an "invisible hand" that shapes product development, but doing so offers no insights or management tools for our use.

If advances are to be made in this research area, there needs to be improved data collection. The first step would be a series of pubic policy decisions that supported the collection and publication of non-financial reporting data at U.S. firms. Although Swedish firms such as Skandia have published an assessment of their intellectual capital stocks as a supplement to their annual reports[77], no U.S. firms have followed suit. Currently, U.S. companies not only have few incentives for collecting data on intellectual capital, but they could possibly face litigation if published data is construed as misleading investors about the state of a company's intangible assets. Without clear reporting standards or "safe harbor" protections[78] for voluntary disclosures, there is little hope for improved data collection and reporting.

As a first step, a safer environment for publishing data on non-financial assets would allow firms to explore this area, and possibly develop pilot programs for investigating the role of intellectual capital. Some policy analysts have suggested that this research effort be coordinated through a

[77] "Visualizing Intellectual Capital at Skandia", *Supplement to Skandia's 1994 Annual Report*, http://www.skandia.com/en/ir/annualreports.shtml

[78] See the recommendations of a Brookings Institution task force on intangibles, Margaret M. Blair and Steven Wallman co-chairs, *Unseen Wealth*, Washington D.C., 2001.

federally-funded center based at the Bureau of Economic Analysis at the U.S. Department of Commerce[79]. Alternatively, joint industry-academia efforts could be expanded to promote research on intangibles and develop pilot programs in different business sectors. For the aerospace industry, the research presented here provides a good starting point not only for understanding intellectual capital, but for defining metrics for further data collection.

### *7.7. Transparency and public finance policy*

At first glance, promoting "more research" may sound like a self-serving recommendation from academia. However, businesses will also directly benefit from an increased awareness of intellectual capital, greater data collection, and public dissemination of information on intangibles. Despite the emphasis on knowledge-based assets in today's economy, there is a lack of transparency about intellectual capital that inevitably hurts businesses – and the aerospace industry in particular.

Unfortunately, companies today face a handful of inconsistencies about knowledge-based assets in U.S. tax policy and intellectual property law. Although the economy may have changed, our public policies regarding knowledge-based assets have not. The failure to update these policies, whether intended or unintended, nonetheless impacts how resources are allocated in the corporate environment. These inconsistencies include:

- *Investments in intellectual capital are expensed.* While investments in business machinery are capitalized and depreciated over time, investments in many intangibles, including training and R&D expenditures, are expensed. Not only does affect the tax implications of investments in intellectual capital, but suggests that investments in intellectual capital have no value beyond the quarter in which they are incurred.
- *Intellectual property purchases are capitalized.* To strike a comparison, purchases of tangible intellectual property, such as patents and copyrights, are treated as investments and are capitalized as assets on the corporate balance sheet.
- *Business method patents.* As discussed in the literature review, there has recently been a flood in requests for business method patents, in effect taking aspects of a firm's structural capital and making it a tangible, licensable asset. These efforts continue to blur the formal distinction between intellectual capital and tangible assets on the balance sheet.
- *Goodwill.* Finally, the assignment of a "goodwill" value during corporate mergers and acquisitions is another inconsistency in accounting and tax policy. To address the difference between market and book value at the time of corporate sales, goodwill is a catch-all categorization to assign value to a firm's intangible assets. Although it is a one-time assessment at the time of sale, goodwill is a conspicuous acknowledgement of the tacit value in human, structural, and relational capital that fails to show on the firm's books.

[79] For details of these proposals, see the Brookings Institution policy subgroup recommendations at http://www.brookings.org/es/research/projects/intangibles.htm

If knowledge-based assets form the basis of corporate value in today's economy, then accounting rules and tax policies should be revised to reflect this change. A number of efforts, including the New Economy Value Research Laboratory[80] at MIT, investigated methods for valuing intangibles and making tax policy recommendations. Unfortunately, many of these efforts were either axed during the economic downturn, derailed by the recent corporate accounting scandals, or became bogged down in the plodding financial valuation of individual intellectual assets. Any changes in accounting standards or tax policy now seem very unlikely in the near future.

It can also be argued that the public policy failure to address these issues has had a negative impact on aerospace firms in particular. If the aerospace industry is truly rich in intellectual capital, then it could benefit from greater transparency about knowledge-based assets in accounting and reporting data. This is because the value of assets – whether tangible or intangible – affects the firm's ability to secure capital in the financial markets. As discussed in the introduction, recent articles in Aviation Week and assessments by Booz-Allen have lamented that the industry has difficulty in raising equity capital, with the cost of credit too high to allow for investments in growth opportunities.[81] Aerospace's ability to communicate its wealth in intellectual capital – to "get the word out" about the value of its knowledge-based assets – is possibly hampered by a lack of industry-wide disclosure about its holdings. Greater transparency about aerospace's intellectual capital for today's operations and tomorrow's opportunities could lead to the infusion of capital that the industry greatly needs.

### *7.8. Sustaining intellectual capital in the Aerospace industry*

As discussed in the introduction, the Aerospace industry's problems are, unfortunately, far deeper than their inability to attract financial capital. Given the reductions in both the commercial and defense sectors, the declining number of development programs, the diminishing experience base, and the demographics of the workforce, aerospace may truly be "losing the recipe" for designing new products. Beyond financial policy, this is a serious public policy concern, with implications for our capability to meet national security needs.

By extrapolation, we can use some of the results from the case studies to shed light on the problem. The capability matrices, combined with the lessons learned from the cases, help to identify some difficulties with creating and sustaining intellectual capital at the firm level, with implications for policy at the governmental level. To be expected, the research does not provide any easy answers for policy makers – the challenge is far too great, and the scope of this research is far too small. However, we can use the research to highlight some important considerations, and make some generalizations about the type of investments that could be made:

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[80] For a news archive on this short-lived program sponsored by Arthur Andersen, see http://mitsloan.mit.edu/news/releases/2000/andersen.html

[81] Scott, William B., *Aviation Week*, Mar.13, 2000 and April 23, 2001, and *U.S. Defense Industry Under Siege--An Agenda for Change*, John R. Harbison et.al., Booz-Allen & Hamilton, Los Angeles, CA, 2000.

- *Investments in human capital.* All of the cases illustrate the difficulty for firms to secure human capital, either in attracting new staff or retaining the staff that it has. One of the fundamental difficulties – the lack of job stability – is an outgrowth of the systemic problem of program instability in the aerospace industry.[82] Again, there are no easy answers here; policy makers must consider how funding instability can erode the human capital base of the industry, and what level of investment is needed to sustain this critical national resource. Although investments in structural capital can capture some of this tacit knowledge, the framework and research affirms that it cannot replace the central, vital role of human capital in knowledge and value creation.

  At the firm level, managers can help sustain their human capital by using the capabilities matrices to guide their investments. In the short-term, the cases suggest that the best solution is renting human capital from the outside. Without a means to attract or retain staff, project managers in the case studies tended to rely on retired staff and consultants to "plug the holes" in their human capital base. To create and sustain lasting human capital, the matrices indicate that interdisciplinary experience and dedicated development teams are valuable capabilities where firms should make strategic investments. Promoting cross-training and interdisciplinary experience not only increases the skill base, but allows for adaptability and better utilization of skills across the firm. Corporate yellow pages and other tools that improve human capital utilization can provide an important buffer against this instability.

- *Investments in structural capital.* Corporate managers and DoD clients should judge investments in structural capital by their ability to create lasting value for the firm and the nation. Project data requirements and investments in information technology are two obvious areas for improvement. Rather than creating databases of knowledge for knowledge's sake, the case studies findings emphasize the importance of capturing data that is relevant, accessible, and useful for future projects. Requirements for program documentation, in either paper or digital form, should be judged by these standards of accessibility, relevance, and usefulness in creating value – otherwise, they are a simply a source of waste. At the firm level, managers should consider whether the knowledge-rich lessons learned from the project are being captured, and whether document management systems are providing user-friendly access to these important kernels of corporate knowledge.

- *Investments in relational capital.* On a relational level, the case studies and capability matrices support the recommendations of the Lean enterprise research effort. The emphasis on value at the enterprise level – extending to the importance of value at both national and international levels – can help frame the discussion for determining the best areas for corporate and governmental investment. Building relational capital at this level is akin to the

[82] For a summary of workforce instability, see Cutcher-Gershenfeld, J., et.al., "The Impact of Instability on Employment", Labor Aerospace Research Agenda presentation, LAI Plenary, March 2001. For a comprehensive review of aerospace program instability, also see Rebentisch, E., "Preliminary Observations on Program Instability", LAI White Paper #96-03, Oct.1996, http://lean.mit.edu.

process of identifying value and creating value propositions[83] that include clients, investors, and national (public) interests.

The case study research strongly suggests that higher levels of cooperative involvement between firms and governmental clients lead to greater value creation across the board. Processes and mechanisms that encourage peer-to-peer collaborations between design staff, managers, SPOs, and regulatory agencies can improve product quality, client "buy-in", and client satisfaction. None of the cases suggested that there were any detrimental effects from fostering increased cooperation between aerospace firms and their government clients. Rather, two case studies advocate that public policy should allow for more innovative – and perhaps revolutionary – arrangements between contractors and their government sponsors. The inception of the commercial derivative aircraft project, as well as the successes of the foreign military lease project, were predicated by unique contractual arrangements that established limited partnerships between firm and government client. Although supported by only two data points, the research suggests that policy changes should allow for more experimentation in this area, as cooperative efforts can lead to more value for aerospace firms, their DoD clients, and importantly, the taxpayer.

### *7.9. A checklist of intellectual capital for today's operations*

At the corporate level, how should managers best use the concept of intellectual capital to improve new product development? Although this research has implications for public policy, it primarily speaks to project management and corporate policy. From the beginning, the research goal was to create a tool for managing intellectual capital, with emphasis on the product development process. To this end, the conceptual framework, case studies, and capability matrices all provide insights into the role of intellectual capital in product development. But at a tactical level, how can these results be used to help managers allocate resources and plan their project?

There is no simple recipe for using this research to guide new product development. Project requirements vary, and managers are individuals; each will discover a different technique for applying the lessons from this research. However, it may be helpful to outline a few steps for project planning in light of the research findings – and draw an important connection to other research at LAI.

As mentioned earlier, intellectual capital can be used as a conceptual "lens" for understanding the role of knowledge in firms. However, it's not the only tool in a manger's tool chest. Lean principles – emphasizing the process of eliminating waste and creating value – provide additional tools for understanding how to deliver value to the client, the firm, and other stakeholders in the project.

[83] Earll Murman, et al., *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*, Palgrave Press, p.184, 2002

The connection between lean thinking and intellectual capital is instinctive. Lean's philosophy of an intelligent, knowledge-driven approach to production is a natural complement to an emphasis on knowledge-based assets in today's businesses. Both concepts address the fundamental issue of what defines "value", looking beyond the corporate walls to maximize value creation for all parties involved. In fact, it is this awareness of lean value at the meta-level – the emphasis on the entire "enterprise" – that provides an important connection to the role that relational capital plays in successful product development.

Combining lean thinking with the concept of intellectual capital can help managers identify the critical resources and necessary steps for a successful product development project. These steps draw upon the key principles from both research efforts:

1) *Stakeholder identification and value identification.* As discussed in the LAI text on lean enterprise value[84], the first step in the value creation framework is identifying stakeholder value. Managers should go through the exercise of identifying stakeholders in the project – including the client, suppliers, partners, regulatory agencies, and shareholders – and understand what aspects of the project can provide value for them.

2) *Intellectual capital identification.* Using the concepts of human, structural, and relational capital from the conceptual framework, managers can begin to identify the underlying corporate resources that can be brought to bear on the project. This effort does not have to be exhaustive; it simply is intended to use the "lens" of intellectual capital to highlight the underlying knowledge-based assets of the firm.

3) *Identifying relevant capabilities.* Next, managers should review the capability matrices to identify which capabilities are most important for their project. Although the capabilities from the case studies represent the common threads from the research, they may not be relevant for all projects. For example, projects that do not involve regulatory oversight have little need for developing working relationships within government agencies. Using a low/medium/high scaling, managers can spotlight which capabilities are critical for success in their particular application.

4) *Capability self-assessment.* Finally, managers can utilize the matrices to gauge their capabilities in these critical areas. Using the Level 1 to Level 5 rankings, managers can perform a self-assessment and identify areas for needed improvement. Obviously, managers should focus attention on high-relevance capabilities that received weak grades in the assessment.

By using the steps in this checklist, managers can begin to see if their resources are adequate for the task, as well as anticipate needs that will arise later in the project. Armed with this

[84] Earll Murman, et al., *Lean Enterprise Value*, ibid.

awareness, managers can develop plans for utilizing existing assets, developing new capabilities, or partnering with firms that have the needed capabilities.

In effect, this is a "make-or-buy" decision for intellectual capital – whether the firm should make an investment in developing in-house human and structural capital, or farm the work out to consultants, subcontractors, or partners. For this make-or-buy decision, managers have two additional considerations: the "clockspeed" for intellectual capital development, and the return-on-investment for their decision. First, managers need to consider that developing corporate intellectual capital can take time, especially since structural and relational assets can take years to create and nurture[85]. Secondly, managers need to decide if it's a better investment to develop the firm's capabilities and create intellectual capital of lasting value, or simply farm out the work and satisfy short-term needs. Although this is a common calculus in the workplace, it is the concept of intellectual capital that adds new meaning to the decision. By assessing your intellectual capital, you can make an informed decision about procuring knowledge-based assets – either using what you have, or getting what you need.

Based on this self-assessment, project managers can explore how their human, structural, and relational assets can be leveraged to deliver value for their projects and their clients. Once again, lean principles and intellectual capital are complementary, in that they emphasize a customer-focused approach to creating value. Intellectual capital, and relational capital in particular, must be well-established for managers to not only understand their client's definition of value, but to be able to craft a winning value proposition[86] for all stakeholders involved.

### *7.10. Using intellectual capital for tomorrow's opportunities*

Finally, it's worth noting that intellectual capital is more than just a project planning tool. The concept of intellectual capital, and the insights that it provides, can help shape corporate strategic planning as well. If managers can use this research to guide resource allocation for their projects, then strategic planners can use the same tools to assess whether their human, structural, and relational capital will allow the firm to execute on long-term strategic goals.

Once again, this realization is not new or ground-shaking. Robert Kaplan and David Norton, developers of the Balanced Scorecard, initially considered their framework as a measurement tool only. By developing non-financial metrics, the balanced scorecard was intended to aid managers by creating an improved reporting tool for operations. However, after eight years of

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[85] Procurement of human and structural capital can be either internal (e.g. hire new staff, building operational capabilities) or external (e.g. contracting out to consultants and manufacturers). One is temporary, the other has lasting value. Relational capital, however, is usually internally built over time – although mergers and acquisitions can be a method for buying brand and reputation.

[86] For more on value propositions, see Murman, *Lean Enterprise Value*, ibid.

helping firms develop their own scorecards, Kaplan and Norton realized that balanced measurement's greatest utility lies not in project management, but in strategic management[87].

The same conclusion applies to the concept of intellectual capital – it is a "lens" to examine and critique a company's strategic plan. Using intellectual capital, senior management can assess how their knowledge-based resources "fit" with their overall strategic plan. Armed with this knowledge, they can determine appropriate strategic goals, identify areas for resource acquisition, and allocate the necessary timeframes for intellectual capital development and procurement. In fact, the "clockspeeds" of intellectual capital development may be better suited for long-term planning than short-term operations. Aligning knowledge-based assets – human, structural, and relational – with an organization's strategy may be the most critical component in successful execution of strategy. As Kaplan and Norton point out, many portfolio managers believe that the ability to execute strategy is actually more important than the quality of the strategy itself[88]. Intellectual capital can therefore be a powerful tool for managing strategy and successfully executing it.

Certainly, today's managers have many tools and methods at their disposal for formulating corporate strategy – there is a crushing wealth of books and seminars on this topic. However, the strengths of intellectual capital as a project planning tool are the same strengths that make it a good strategic management tool. First, the categorizations of human capital, structural capital, and relational capital are intuitively appealing and easy to grasp. Because it is conceptually straightforward, the lens of intellectual capital can help managers to frame their strategic thinking outside of the boundaries of their organizational dynamics. Rather than formulating goals based on legacy issues or traditional views of organizational strengths and weaknesses, management can use intellectual capital to self-assess their underlying knowledge-based resources and evaluate their fit with corporate strategy. Hopefully, intellectual capital can serve as a fundamentally different way of thinking, allowing these strategic planners to make objective critiques and identify areas of needed development.

### *7.11. Conclusion*

In today's business economy, intellectual capital is an important concept that has often failed to live up to its hype. Unfortunately, many researchers and practitioners have fallen into the trap of trying to measure individual knowledge assets, without a solid understanding of what intellectual capital is, and how it creates value. Based on the belief that measurement is the first step to management, earlier researchers have mistakenly assumed that measurement must be quantitative and often financial in nature, with many attempts trying to explain the difference between the market value and book value of firms.

[87] See Kaplan and Norton's sequel, *The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment*, Harvard Business School Press, 2000.

[88] Kaplan and Norton, ibid, 2000, p.1.

Financial valuation, however, misses the point by trying to assign dollar signs to individual assets. The verity lies in intellectual capital's application, not in the assets themselves. Knowledge-based assets derive their value through their application, and individual components of intellectual capital, like many tangible assets, have limited intrinsic value of their own. Their value emerges when they are when they are synergistically combined and applied in unique ways to create new products and services. The key to identifying value, then, is not to focus on individual assets, but to look at the capabilities that these assets provide.

Instead of "bean-counting" their intellectual capital, aerospace managers are most concerned with how to use it. Hopefully, this research provides some guidance. It offers a simple framework – one that creates a coherent mental model of resources, capabilities, and organizational learning within the firm – that captures the dynamic nature of knowledge assets. The framework is the first contribution of this research, since understanding intellectual capital is the first step to identifying and using it. With this understanding, intellectual capital can be a "lens" to visualize intangible assets that lie beneath the surface.

This conceptual understanding is supplemented by the lessons learned from the case studies. These lessons, distilled in the capability matrices, provide managers with a tool for using their knowledge assets for product development. Combined with lean principles, managers can the checklist above to determine how to best use their internal resources – their human and structural capital – as well as how to also use relational capital to deliver value across the enterprise.

And as discussed above, the tools from this research also allow senior management to assess the "fit" of its knowledge-based assets with the corporate strategic plan. Potential projects can be evaluated through the lens of intellectual capital, and areas for asset improvement can be identified. The three products of this research – the framework, case studies, and capability matrices – provide tools that both managers and strategic planners can use, allowing them to perform the basic functions of gauging, allocating, and growing their corporate resources and capabilities.

Beyond corporate governance, the framework and case studies also have implications for public policy. By highlighting the importance of knowledge-based assets in the aerospace industry, the research suggests that policy analysts should consider sustaining human capital as a central investment in national capabilities. Government oversight of aerospace programs should also consider how structural capital and relational capital can be fostered in the industry, and whether contractual requirements promote value creation, or simply add waste. Finally, financial policy should allow for greater transparency for reporting of knowledge-based assets, and further intellectual capital research should be funded to collect industry-wide data as a public good. If nothing else, this research should serve as a call for further research – for given the importance of knowledge-based assets in today's economy, it's clear that better data and tools are needed in this area.

In summary, successfully managing intellectual capital can be more of an indirect art than a precise science. Organizational theorists have found that it is difficult to directly manage discussion and knowledge transfer between employees; rather, it's easier to concentrate on creating the right environment that promotes communication and collaboration. Similarly, trying to manage the invisible hand of intellectual capital can be like trying to "herd cats" – instead of concentrating on individual asset management, it requires a more holistic approach to the task.

The findings from this research confirm that managers need to keep their eye on the big picture, making sure they have the right mix of intellectual capital to achieve their goals. Perhaps this is nothing new – most managers are well aware of the need to consider both detail and breadth in their projects. And many of the lessons from this research are nothing new as well. Good managers will notice that the research findings are not ground shaking, but simply common sense. The contribution of this research, however, is two-fold: first, it provides an improved conceptual understanding of intellectual capital, one that can be generalized to different projects and applications. Second, it's useful in its specificity – the matrices and the guidelines provide explicit tools for measuring and managing the intellectual capital of the firm.

Taken as a whole, the framework, case studies, and capabilities matrices will hopefully provide some much-needed insights about a fuzzy topic – the role of knowledge in firms. Although the research offers some explicit steps for managers, it is only a guideline. Every application is unique, and no tool can provide a "silver bullet" for completely understanding the myriad of factors that contribute to project success or failure. However, if knowledge is power, then perhaps these findings will help us efficiently tap into its full potential.

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