17 AGILITY AND INFORMATION TECHNOLOGY DIFFUSION IN THE SEMICONDUCTOR INDUSTRY

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Abstract *New product development in the semiconductor industry is characterized by products with a high level of intellectual property content, and ever-decreasing product development cycles, designed by very scarce engineering talent. The foundation of the success of many semiconductor companies is their ability to respond quickly to turbulent market conditions. This ability is contingent on intra-organizational and interorganizational factors, which will be described in this paper. Firms are attempting to overcome these agility-related challenges by developing and deploying IT-based responses. This paper takes a practitioner perspective. The authors have a combined experience of over 35 years in the semiconductor industry.*

Keywords Agility, IT diffusion, clockspeed, new product development, knowledge management systems

1 INTRODUCTION

The semiconductor industry is concerned with designing and manufacturing integrated circuits. Integrated circuits are the fundamental building blocks used in IT systems. Examples of integrated circuits include computer memory chips and computer processor chips. The industry has grown considerably over the last 30 years to the point where it is now constitutes over $100 billion in world-wide sales. This growth has been achieved in a very dynamic, turbulent operating environment.

To address these challenges, new product development (NPD) organizations in the semiconductor industry need to develop and maintain the ability to embrace change. Agility has become a significant factor in a firm's survival during these times of increased competition and economic uncertainty in the industry.

2 AGILITY IN THE SEMICONDUCTOR INDUSTRY

An industry's *clockspeed* is defined as a measure of the dynamic nature of that industry and depends on the nature of the products, manufacturing process turnaround times, and organization clockspeed (how quickly concepts are translated into products) (Carrilio 1999; Mendelsohn and Pillai 1999). The basis for a fast clockspeed firm's survival is the ability to move quickly from one temporary advantage to another (Fine 2000). This form of agile behavior is particularly important in the semiconductor industry, which has been characterized as having a particularly fast clockspeed (Fine 1998).

A driver of industry clockspeed in the semiconductor industry is Moore's law, an historical observation by Intel executive Gordon Moore that the market demand for functionality per chip doubles every 1.5 to 2 years. Moore's Law has been a consistent macro trend and key indicator of successful leading-edge semiconductor products and companies for the past 30 years. Given that Moore's Law drives the clockspeed of the semiconductor industry, the ability to adapt to change has become a significant factor in a firm's survival. The factors impacting such agile behavior will be described in the next section.

2.1 Agility: Interorganizational Factors

Grant (2000) and Ilvari and Linger (1999) have identified a number of interorganizational factors pervasive in knowledge-based industries such as the semiconductor industry. This section will explore the impact of these factors on a firm's agility.

2.1.1 Competing for Standards

Over the last two decades, firms have been more inclined to form collaborative projects with customers, competitors, and government agencies to achieve a standardization goal. For instance, a firm may want to work with an internationally recognized center-of-excellence in an academic institution with which it has no formal relationship. In such cases, knowledge has to be combined from participants across multiple collaborating organizations.

2.1.2 Vendor/Customer Relationships

Collaboration between semiconductor NPD vendors and their customers has increased in response to global competition and increased complexity as the semiconductor clockspeed drives technology into uncharted territory. Semiconductor companies continue to deploy technical semiconductor design expertise locally to customers throughout the world to ensure collaboration.

2.2 Agility: Intra-Organizational Factors

NPD organizations need to rapidly transfer knowledge across internal organizational boundaries, so as react quickly to either technological or commercial discontinuities. The factors at play here include virtual NPD teams and intra-organizational collaboration.

2.2.1 Virtual NPD Teams

NPD activities that span geographical boundaries have become commonplace in the semiconductor industry, as NPD has been globalized. Some of the challenges posed by distributed teams may arise from cultural differences. Culture

- shapes assumptions about which knowledge is worth managing (Sackmann 1992)
- defines relationships between individual and organizational knowledge (von Krogh and Roos 1996)
- creates the context for social interaction (Graham and Pizzo 1996)
- shapes the processes by which new knowledge is created (Hayduk 1998)

Additional challenges include differences in native language, which mitigate against the communication of technical nuances, and a scarcity of coincident working hours, caused by time-zone differences.

The response to these challenges is for the lead project personnel to spend a lot of time, upfront, documenting the project specifications and partitioning decisions. The authoring, review, and revision of such documents reduces flexibility and responsiveness, and therefore diminishes agile behavior.

2.2.2 Intra-Organizational Collaboration

Many NPD projects require cross-functional collaboration. The nature and importance of this collaboration is described by Wheelwright and Clark (1992) as follows: "Outstanding product development requires effective action from all of the major functions in the business. The firm must develop the capability to achieve integration across the functions in a timely and effective way" (p. 165).

In addition to cross-functional collaboration, semiconductor NPD organizations must collaborate between business units in order to provide responses to innovative customer needs which span traditional business unit responsibilities. This represents an agile capability to meet changing market requirements.

3 IT SUPPORT AND DIFFUSION IN THE SEMICONDUCTOR INDUSTRY

Firms have looked to IT to help develop a response to the agility challenges described in section 2. The IT response has included simulation and modeling utilities, support for knowledge sharing and peer reviews.

3.1 IT Support of Agility in Semiconductor NPD Processes

3.1.1 Modeling and Simulation

From the financial modeling made possible by spreadsheet applications to the use of yield management applications in the hotel, car-rental, and airline industries, the adoption of modeling and simulation applications in NPD has transformed industries (Schrage 1999). In the semiconductor context, modeling and simulation are core activities of the circuit design process and support agility in respect of customer interactions, communication, and collaboration. Modeling and simulation fulfills a number of functions.

- They provide the ability to verify whether the design task is successful in comparison to the desired specification. This is the role of functional simulation and verification.
- The ability to iterate quickly on the outcome of a simulation facilitates design changes in an agile market, as targets change during NPD.
- The role of rapid iteration is also an enabler of innovation, as the engineer reflects upon the outcome of a simulation, leading to insights regarding the operation of a design.
- Communication of complex ideas (e.g., the consequences of various design decisions) is enabled via third party interaction with the model.
- Peer reviews are facilitated by enabling a critique of modeling methods and simulation outcomes and a review of design specifics.

The ability of the simulation model to act as an archetype facilitates communication and collaboration, acting as a frame of reference around which differences in understanding and context can be highlighted and explored. This brings the following benefits:

- Within a global team, the challenges of virtual NPD teamwork outlined in section 2.2, such as differences in context and understanding, may be managed.

- The interorganizational factors affecting semiconductor NPD vendors and their customers, as outlined in section 2.1, are reduced as they share a common understanding of the design as it progresses during the design process.

3.1.2 High-Level Design Abstraction

A significant development in support of agility has been the move since the early 1990s, toward high-level design abstraction for digital designs. This high-level design abstraction allows designs to be described in text form, rather like software design. Akin to the "agile manifesto" in software development, continuous delivery of working designs is facilitated by a high level of automation brought to the design process by IT. Such a process allows a near-final design to be produced regularly, incorporating the latest design changes, which may then be evaluated with respect to the requirements. It is not unusual to see a new design every day in order to check consistency as the design progresses.

3.1.3 eCatalogs

Learning is a key activity in the development of a firm's ability to adapt and change. "Conventional explanations view learning as a process by which a learner internalizes the knowledge, whether 'discovered,' 'transmitted' from others, or 'experienced in interaction' with others" (Lave and Wenger 1991, p. 47). The knowledge being sought is, in fact, knowledge about knowledge or *meta-knowledge* (Kehal 2002; Swanstrom 1999). The focus of much attention in agility-related IT initiatives in the semiconductor industry is on meta-knowledge.

An eCatalog, in this context, is an application that generates a list of previously designed products in the NPD community. Such eCatalogs enable NPD staff to quickly find out if previously designed products are similar to those currently under development. Problems identified in the NPD process that are addressed by eCatalogs include

- a lack of awareness of what previously designed circuit blocks had been created and might be available for reuse in future projects

- the need to provide a mechanism by which NPD staff can easily make their products more easily "discovered" by members of the NPD organization outside of their own organization unit

The meta-knowledge embedded in eCatalogs allows the global NPD organization to leverage its knowledge assets, allowing the flexibility in product design beyond that which could be achieved by one design team. As such, eCatalogs provide a response to the intra-organizational challenge of cross-business unit collaboration.

3.1.4 NPD Design Repositories

A repository, in this context, provides a store of previously designed products that could be reused. Each of the repository's elements has an extensive support kit associated with it (i.e., contextual information about previous usage, data formats compatible with existing NPD systems, validation data, interface information, etc.). The goal of such repositories is to provide a library of robust and supported reusable circuit designs available for download, obtained from both internal and external sources. They contain previously designed products packaged in a format suitable for delivery as intellectual property to either internal groups or external groups (or both). Their purpose corresponds, generally, to what Hansen et al. (1999) termed a *codification* strategy where the value of the repository lies in connecting people with reusable codified knowledge or to what Swan et al. (1999) termed a *cognitive* strategy where the primary function of the repository is to codify and capture knowledge so that the knowledge can be recycled.

Like eCatalogs, design repositories facilitate the leverage of information processing (IP) across the organization, providing a response to collaborative challenges. However, in contrast to eCatalogs, design repositories require a significant up-front investment in preparation of the support kit associated with each piece of IP.

3.1.5 Peer Reviews

Peer reviews are an integral part of an NPD process, and have been characterized as a justification activity following the creation of an archetype (Nonaka and Takeuchi 1995). In this context, an archetype may be thought of as a prototype, which may be in the form of a model. The peer review activity facilitates the justification of design decisions and the design and verification activity (Bergquist et al. 2001). In this way, the knowledge of a group of designers may be brought to bear on the design.

The medium for the peer review is the model and associated simulation results. During the peer review process, the model and the simulations may be scrutinized for validity and applicability to the design context. The peer review supports agility by enabling the designer to externalize and illustrate the design outcomes, allowing collective experience to be brought to bear in validating the design. A successful peer review process will reduce or eliminate unplanned design iterations which cost lost time-to-market and associated opportunities.

3.2 Diffusion of IT Support of Agility in the Semiconductor NPD Process

This section examines the extent to which the systems described previously have been diffused throughout the industry.

3.1.1 Modeling, Simulation, and High-Level Design Abstraction

Throughout the last two decades, the leading firms in this industry have been pioneers in the development of modeling, simulation, and high-level design tools for in-house use by their own design teams. There is little doubt that the availability of advanced technology in this area has been an advantage to these companies. Today the complexity of the design tasks needed for consumer applications, such as mobile devices and gaming technology at an affordable price, has reduced the ability of even the largest companies to develop their own IT for simulation, modeling, and high-level design.

With over 100 significant IT product offerings in this space, and annual revenues of the top two software vendors in this area of $2.4 billion in fiscal year 2003, there is extensive diffusion of these tools throughout the semiconductor industry.

3.2.2 eCatalogs and Design Repositories

As a response to the agility challenges of turbulent markets and product complexity, eCatalogs and design repositories have seeded a flurry of IT development activity in semiconductor design companies over the past decade. Based upon the objectives of intellectual property packaging and distribution on the one hand, and enabling collaboration between experts on the other, the aim is to increase agility in the NPD process.

Design repositories require engineering staff whose role is to make the design IP flexible and applicable to a variety of situations. This involves parameterization of the design and implementation of standard interfaces. For example, certain processor cores have achieved a high degree of standardization, fueled by their application in mobile products. The interfaces and programming language of these cores have become accepted industry wide and, as such, the up-front preparatory work of the design repository engineering staff can be leveraged into new projects. Therefore, repositories have been successful in regard to this "digital IP." They have been less successful for "analog IP," which tends to be less standardized.

eCatalogs support the communication and collaboration required for all IP types, but have been more applicable to analog IP because of the difficulty in standardizing. No matter how well packaged the IP is, however, the experience is that some communication between the IP user and the original developer is always required, which goes against the intention of the design repository as a source of reusable codified knowledge.

It takes time and effort to document the IP for cataloging and to prepare designs for a repository; issues such as motivation, reward, and group culture have mitigated against the wholesale diffusion of these applications.

4 CONCLUSIONS

This paper has given practitioners' perspectives on agility and IT diffusion in the semiconductor industry. Forces impacting agility in the industry were described. Inter-organizational factors include vendor/customer collaboration, management, and standardization efforts. Intra-organizational factors include globally distributed teams and intra-organizational collaboration. IT-based approaches to supporting agility were described, including modeling, simulation, and high level design utilities, eCatalogs, and design repositories. Observations were made on the extent to which these systems have successfully diffused throughout the industry. Modeling, simulation and high-level design utilities were seen to be central to the semiconductor NPD process, and therefore widely diffused, supporting agility by providing the capability to continuously integrate design changes. Additionally, models were seen to act as an archetype, which provides a response to the agility challenges described. The successful diffusion of eCatalogs and design repositories were seen to be mixed. Design repositories were successfully diffused for digital IP, which suits standardization and can be leveraged over time. The difficulty in standardizing analog IP made it less applicable to repositories and more applicable to eCatalogs, which provide meta-knowledge regarding the design and its developer.

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