The Dynamics and Architecture of Value Networks – The Case of the Medical Imaging Industry

by

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Submitted to the Alfred P. Sloan School of Management in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

With the increase in strategic alliances and acquisitions, the firm needs to be studied in the context of the network of relationships in which it is embedded. This network not only extends the capabilities of the firm by establishing channels to access additional resources but it also creates additional constraints that have to be accounted for. This fundamental view is the backdrop of this research on the dynamics of the diagnostic medical imaging industry.

This thesis explores a variety of network-based approaches to characterize the dynamics of the medical imaging industry. After reviewing the literature on the subject of alliances and inter-organizational networks, we describe the medical imaging industry in the United States. For our analysis, we have compiled a list of alliances and acquisitions launched in the last 15 years and used that list to create an overall network for the industry where each node is an industry subgroup. Along with the visual representation, we have compiled a number of network-based statistics such as distribution of sub-industry membership and centrality. We have examined the trends of those metrics in three time periods, 1980-1989, 1990-1999, and 2000-2003 and related those trends to the information gathered through several interviews with industry experts. Those trends are consistent with the consolidation that has taken place in the industry in the last 10 years. However, they also show the emergence of new centers of activity such as the medical services industry segment. Overall, this network model provides a powerful framework to “visualize” the internal structure of the industry.

Leveraging on the main findings revealed by the network-based analysis, we put forward a system dynamics model that combines the main trends highlighted by our research. The model is the basis for a discussion on the potential evolution of the medical imaging ecosystem. While further centralization is expected, we anticipate that the role of the medical service industry segment and the contrast agent manufacturers may significantly weaken this centralization.

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2
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Finally, all my gratitude goes to my wife Isabelle and my sons Nicolas and Lionel. They have provided me with love, constant support and encouragement during this year.

“Throw yourself and the net will appear”  Zen proverb

“If technology doesn’t seem like magic, it’s probably obsolete”  Birthday card
# Table of Contents

1. Introduction .................................................................................................................. 8

2. Alliances, Acquisitions and Networks: A Review ......................................................... 10
   2.1. Alliances and Acquisitions .................................................................................... 10
      2.1.1. Alliances .......................................................................................................... 10
      2.1.2. Acquisitions ..................................................................................................... 11
      2.1.3. Alliance types ................................................................................................. 12
   2.2. Networks and Constellations ................................................................................. 15
      2.2.1. Social networks ............................................................................................... 15
      2.2.2. Inter-organizational networks ........................................................................ 18
      2.2.3. Constellations ................................................................................................. 19
   2.3. Rationale for cooperation ..................................................................................... 20

2.4. Strategic Views ........................................................................................................... 22

2.5. A Dynamic View ....................................................................................................... 25

3. The Medical Diagnostic Imaging Industry ................................................................... 28
   3.1. A Brief History ....................................................................................................... 28

3.2. Key Market Characteristics ....................................................................................... 30
      3.2.1. Technology trends ............................................................................................ 36
   3.3. Industry Attractiveness .......................................................................................... 39

3.4. Overview of Incumbents ........................................................................................... 41

4. Framework ...................................................................................................................... 44
   4.1. The Data .................................................................................................................. 45
      4.1.1. Caveat ............................................................................................................... 45
      4.1.2. The players ....................................................................................................... 46
      4.1.3. Alliances and acquisitions ............................................................................ 48
Tables

Table 1: Types of cooperative agreements ordered in terms of perceived inter-organizational dependence. .......................................................................................................................................................... 12

Table 2: Optimum entry and evolution strategy to new markets.......................................................................................................................... 24

Table 3: Classification of firms in the inter-organizational network into broad categories and industry sub-group based on Hoovers primary industry label, along with the percentage.... 48

Table 4: Summary centrality evaluation based on the questionnaire in Appendix C. ................. 64

Table 5: Data and numbers for medical imaging modalities .................................................................................................................... 90

Table 6: Categories of relationship used to classify all alliances and acquisitions. Based on the types provided on the Recap database, with the addition of the “lead deployment” and “compatibility alliance”........................................................................................................... 92

Figures

Figure 1: Double helix model from Fine 1996................................................................................................................................. 25

Figure 2: Value Chain Analysis Framework proposed by Kawashima (2002).................................................. 26

Figure 3: Revenues per modalities from 1999 to 2001 (DH 2003)......................................................................................... 31

Figure 4: Porter’s five forces for the medical imaging industry .................................................................................................. 40

Figure 5: Trends in alliances and acquisitions in the 1980-2003 period. ......................................................... 51

Figure 6: Mix of alliance and acquisition partners in terms of broad industry categories over the 3 time periods........................................................................................................................................ 52

Figure 7: Non-metric MDS representation for the network of alliances and acquisitions during the 1980-2003 period using Ucinet (Bartolli 2002). ................................................. 54

Figure 8: Network graph of relationships or sub-industries during the period 1990-1999 .............. 56

Figure 9: Network graph of relationships or sub-industries during the period 2000-2003 ............ 57
Figure 10: Centrality flow betweenness for the sub-industries for the periods 1980-1989 and 1990-1999.................................................................................................................................................. 59

Figure 11: Network of medical imaging industry aligned along the vertical (supply) and horizontal axis (complementor). Acquisitions are indicated with curved arrows.............................................. 67

Figure 12: Overall system dynamics model of the medical imaging industry ........................................ 72

Figure 13: Basic loops........................................................................................................................................ 73

Figure 14: Loop showing the impact of increased vulnerability ................................................................. 74

Figure 15: Effect of improvements in imaging technology........................................................................... 75

Figure 16: Effect of price sensitivity on centrality......................................................................................... 77

Figure 17: The development of new clinical applications........................................................................... 78

Figure 18: Decentralization forces ............................................................................................................. 79
1. Introduction

The recent rise in strategic alliances and acquisitions has led to a growing interest in “value networks”. It is becoming increasingly important to understand how relationships outside the traditional boundary of firms shape their overall conduct and profitability. This question has triggered a large body of literature on inter-organizational networks. The literature suggests that the “social network” in which firms are embedded has a significant impact on the performance of firms. Networks of relationships bring opportunities (i.e. “social capital”) as well as constraints. Opportunities derive from the structure of the network, the position of a particular firm in that structure, and the patterns of relationships developed. On the flip side, the inclusion in a network can limit a firm’s ability to extend to other technical areas or engage in other relationships.

This framework is particularly relevant to the study of the diagnostic medical imaging industry. This industry is highly innovative; it delivers a dream that has haunted generations before us – i.e. the ability to look inside the human body. This dream came true over a 100 years ago and innovations have flourished since then – some more dramatic than others. Today, medical imaging is widely used.

Recent developments and commercialization result from complex patterns of alliances and acquisitions which reflect the highly multi-disciplinary characteristic of the industry and the necessity for complementary assets. These trends have also been compounded by issues of regulations and re-imbursement policies.

This research attempts to address the following questions:

- To what extent does a network centric framework provide an accurate view of the

---

1 The “social” terminology used in this context is a reminder of the fact that one of the largest contributors to that area of research is the field of social networks from which inter-organizational researchers have not only borrowed the terminology but many of the tools.
diagnostics medical imaging ecosystem? Does it help identify “key” actors and their roles?

- Can this network centric view help identify some of the industry dynamics? Does it help detect shifts in network locus? What do these shifts indicate?

- Finally, by modeling some of the dynamics uncovered by the network-based analysis, can we anticipate future trends?

As we address these questions, we will underscore the role of alliances in extending the capabilities of the firm as well as the impact of networks on the conduct of the firm. This paper is organized around five main sections. Section 2 presents a comprehensive literature review. The following section (Section 3) provides an overview of the diagnostic imaging industry with a brief history of the imaging modalities and recent trends in that industry. Section 4 presents the analysis framework and our suggested mapping of the industry structure. The data used for this analysis is introduced and several network “metrics” are investigated. Section 5 explores trends in the medical imaging industry and focuses mainly on the overall industry structure and on its sub-groups. Section 6 offers a system dynamics model presenting our main findings. This model is also used to anticipate different scenarios for the future structure of the industry.
2. Alliances, Acquisitions and Networks: A Review

In the last 15 years, collaboration between firms or groups of firms has been an integral part of business strategy. Partnerships have brought together firms in direct competition and have blurred the lines between cooperation and competition — thus redefining the traditional boundary of the firm. The delivery of many goods and services is now the result of a complex interplay between many players, each adding value to the final product. The essence of the value network concept is to understand the relationships between key players in a network and to assess how each one contributes to the overall value of their network. The value network provides a framework to understand what brings a group of firms together to create the industry ecosystem.

The value network concept draws on several bodies of literature. Our review focuses first on the 2-firm relationships (dyads) — the building block of an inter-organizational network. These relationships can cover a wide range of alliances from simple collaboration with low contractual content to full merger. As we shift our focus to networks with multiple relationships, we describe the contribution of the social networks literature and explore the benefits of a network centric view. The following section (Section 2.3) highlights factors that contribute to the establishment of a relationship; we will then discuss strategic intent and present frameworks used for analyzing strategic alliances. Finally, we conclude our review by examining two models of industry dynamics.

2.1. Alliances and Acquisitions

Alliances and acquisitions are the main building blocks of inter-organizational network. Our motivation in examining both relationships is that in many instances, they indicate similar strategic intent, with different degrees of intensity.

2.1.1. Alliances

Our definition of an alliance, consistent with the literature (Nohria 1992, Gomes 1996), is one of an
incomplete contract between two entities where many gaps and details are left unresolved. These incomplete contracts provide an attractive alternative to complete contracts which can be impractical or too costly (Gomes 1996). The alliance defines how the contract is implemented to achieve the goals set by both parties. In other words the alliance is an opportunity for two firms to go beyond their short-term interest and work together on specific long-term goals. Given the intrinsic incompleteness of an alliance contract between two entities, the role of trust is a critical factor in insuring that both parties act for the common benefit. Another critical factor is the perceived benefit that the alliance adds to both entities – i.e. the overall perceived benefits must exceed the sum of the parts. Both these factors (trust and perceived benefits) affect the long-term success of an alliance.

The extent to which an alliance provides benefits (and the amount of those benefits) is subject of debate. One research assesses that overall, 20% of yearly revenues generated by firms result from alliance activities (Freidheim 1999). This fact however does not answer the question of whether alliances in general create or destroy value. In an earlier article Hagedoorn (1994) claims that most benefit is extracted from technology alliances.

Alliances, although attractive in reaching some goals, come along with uncertainties and hidden costs. This problem can be especially acute in the case of a technology partnership if the partner has the capacity to reproduce the technology of the innovator and to become a competitor (Teece 1996). In this context, firms with more experience in alliances have been shown to be more successful in profiting from the alliances (Anand 2000).

2.1.2. acquisitions

In contrast with alliances, the definition of an acquisition is straightforward: a firm is acquired as soon as more than 50% of its assets are controlled by another company. While the transactional cost of an acquisition is typically much higher than that of an alliance, some of its benefits are clear: control is transferred in an un-ambiguous way and an acquisition provides a very speedy and cost effective way of acquiring new technological competence (Roberts 1985).
2.1.3. Alliance types

Alliances can take various forms – ranging from a simple supply agreement to a complex joint venture. Table 1 provides an exhaustive list of all possible types of alliances in increasing order of perceived inter-dependence between the two entities (Contractor 1988).

<table>
<thead>
<tr>
<th>General Class of Alliance</th>
<th>Sub-types</th>
<th>Comments</th>
<th>Inter Dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier</td>
<td>Component supply Distribution Manufacturing</td>
<td>Component supply, contract assembly, buyback agreements</td>
<td></td>
</tr>
<tr>
<td>Licensing</td>
<td>Patent Know-how Cross-license Exclusive</td>
<td>Can include simple patent licensing, franchising or licensing of know-how.</td>
<td></td>
</tr>
<tr>
<td>Collaboration</td>
<td>Compatibility Consortium</td>
<td>Assume minimal capital investment</td>
<td></td>
</tr>
<tr>
<td>Service agreement</td>
<td>Corporate VC</td>
<td>Refers to the investment from one company to a smaller one.</td>
<td></td>
</tr>
<tr>
<td>Equity investment</td>
<td>Development R&amp;D Marketing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partnership</td>
<td></td>
<td>Usually implies the creation of a separate corporate entity</td>
<td></td>
</tr>
<tr>
<td>Joint venture</td>
<td>Regular Educational</td>
<td>Assets purchased resulting in complete control</td>
<td></td>
</tr>
<tr>
<td>Acquisition</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Types of cooperative agreements ordered in terms of perceived inter-organizational dependence.

Supplier – The supplier relationship is typically an arm-length relationship with little strategic commitment from either party. Generally, the product or component is integrated by the acquirer into his offering. However, supplier relationship can come in other flavors such as distribution and manufacturing agreements. In a distribution agreement, the product is distributed by the other party without modification or re-branding. This type of agreement allows a distributor of a particular
asset (e.g. X-ray machines) to realize part of the value through its specialized distribution system – i.e. distributing complementing technologies (e.g. CT scanner) from another vendor without the need of manufacturing this product. These types of agreements provide the distributor with the opportunity to learn about the market for the new product and have been extensively used in the medical imaging industry (Mitchell 1992). In a manufacturing agreement the third-party is not providing one of its generic products but manufacturing a particular design. While supplier relationships are generally associated with a low degree of dependence, the degree of commoditization of the particular component is a key factor that can affect the balance of the relationship: the supplier of a generic product has clearly less leverage than the supplier of a unique, well differentiated product. A well known example is the case of Intel which has been able to use that leverage to have their “Intel Inside” label put on every PC.

Licensing – Licensing can be looked at as a supplier relationship where the authorization of using some specific IP property is extended to third parties. Licensing typically involves the use of patented techniques; these agreements can be exclusive and thus insure that no other party than the provider of that IP can use it. Licensing agreements often involve royalty fees. This approach has been extensively used by companies (e.g. Microsoft) as a mechanism to promote a particular technology and try to establish a de-facto standard (Roberts 2001, Gaver 2002). The main advantages of licensing are the rapid access to new technology and the reduced financial exposure. On the other hand, licensing is not a substitute for competence and the licensee company has to accept an increased level of dependency.

Collaboration – In collaboration we include relationships where two firms agree to join forces in certain areas with minimal capital investment. Examples of collaborations are compatibility agreements where the two firms agree to work together to insure that their products will be able to interface with each other. This type of collaboration is popular in the medical imaging industry where hospitals often require that devices from different vendors are able to interface with each other. Another popular example is a consortium created to develop a new standard. A consortium
usually involves many players, with a variety of interests.

**Equity investment** – Venture capital means that a company invests in another company for some stake in the equity and, in some cases, for the right to sit at the board. Beyond the purely financial interests, the main driver for a company to engage in such a relationship is to get a “window on technology” along with the option to acquire the technology in the future (Roberts 1985). These relationships however, remain fairly passive and have little direct impact on both partners especially when they are limited to the provision of funds.

**Partnerships** – Partnership imply stronger relationships between the two players, with both partners pooling significant resources (funds and/or human capital) to achieve a common goal. The focus of those partnerships can vary significantly from acquisition of technology competence to joint-marketing. While the market for technology is relatively efficient, the market for competence is not (Pistorius 1997): partnerships provide an attractive way for companies to “borrow and internalize” new technological competence. Similarly, marketing expertise from one of the parties can provide a valuable asset for a small company with limited resources.

**Joint venture** – Joint venture refers to the creation of a separate company whose equity is controlled by both partners. Joint ventures imply the complete integration of two distinct groups with their respective expertise and culture, into a single entity: in that sense, joint ventures represent a very high level of interdependence. A well documented example is the case of CPS, a joint venture between Siemens Medical Systems and CTI PET established in 1988. In 1999 CPS reported a clinical study demonstrating the first combined PET / CT system that takes advantage from a single scan of the benefits of both modalities and has the major benefit of showing both physical and chemical information at once, allowing for earlier detection of diseases.
2.2. Networks and Constellations

Researchers agree that analyzing a firm solely in terms of its strategic alliances is overly narrow and that a systemic approach is more appropriate. Barley (1992) summarizes this as follows:

> Not only are organizations suspended in multiple, complex, and overlapping webs of relations, but the webs are likely to exhibit structural patterns that are invisible from the perspective of a single organization caught in the tangle. To detect overarching structures, one has to rise above the individual firm and analyze the system as a whole. (Barley 1992)

The 1990s have been marked by a growing interest in network perspectives to the study of organizations. In a well read anthology on the topic, Nohria (1992) attributes this new enthusiasm to the convergence of three main factors. First, the competitive unit has moved away from the firm to the firm within its network of allies, suppliers, etc. Second, the combination of technological maturity and the constant pressure on costs has forced most industries to modularize their production or services, resulting in better ability to outsource or leverage from available suppliers. Lastly, the field of network analysis has greatly matured due in part to the increased interest in social networks.

Under this impulse much has been written on how the position of a firm in inter-organizational networks impacts its behavior, its performance and ultimately, the competitive landscape in which it is embedded. We will briefly present some of the main contributions of the social network field and introduce major advancements in inter-organizational networks and constellations.

2.2.1. Social networks

Research on social networks is a cornerstone in the inter-organizational networks research. Social network analysis, initiated by sociologists with a strong inkling for mathematics, has reached mainstream in the 1970s and has since then been used extensively as an analytical tool to study organizations and more recently inter-organizational networks. The broad assumption in social network analysis is that actors (individuals, groups, firms) are linked together by a set of social relationships (friendship, report, exchange of goods, exchange of services).
Social capital – Social capital refers to the actual or virtual resources that an individual or a group accrues from having a well established network of relationships. In that sense, “the network serves as an important function in the development of social constraint directing information flows in the building and maintaining of social capital.” (Walker 1997). Beyond the access to resources, social capital can be viewed as an asset in that it improves cooperation by providing within the network of relationships a common set of implicit rules and norms that reduces the risk of purely opportunistic behavior from one member of the network. The “quality” of those rules and norms translate directly into higher level of trust and reputation giving members incentives to risk greater investments. In counterpart, social capital acts as a constraint in that it limits the range of actions that a member can take and more specifically, it reduces the set of new relationships members can engage in. The concept of social capital extends naturally to inter-organizational networks and provides a powerful framework to analyze the tradeoffs between resources and constraints. Some of the implications relate to the structure of the network in which a firm is embedded: in a completely “open” network where the firms are not extensively connected to each other, norms of cooperation are not well established and social capital is therefore low. On the other hand, “closed” networks with extensive relationships between all actors have high social capital. This structural difference and its impact on social capital will become key as we examine the structure of the medical imaging industry.

Weak ties and structural holes – In contrast to social capital, weak ties and structural holes emphasize the opportunity that can be created for entrepreneurs by exploiting the existing structure of a network. The concept of weak ties introduced by Granovetter (1973) has attracted particular attention. The assertion, generally supported by subsequent research, is that weak ties can play a more important role than strong ties in understanding certain phenomena within a network. This argument rests on the assumption that strong ties are more likely to tie similar members of the network and therefore be less of a channel for innovation. A weak tie on the other hand represents in many cases a tie with a new social network outside the direct access of the network member: in that sense the weak tie is a “bridge” to resources of a different kind that have so far been untapped.
This view is particularly important as it provides a counter-argument to focusing exclusively on strong ties or central firms. For Burt (1992) the advantage is created for an actor who can serve as a broker between distinct sub-networks and not within dense regions of relationships. Burt refers to these “in-between” regions of sparse activity as structural holes: these holes present in essence entrepreneurship opportunities where the returns are higher than in other areas of the network because the position of broker provides a potential for arbitrage in markets for goods and services (Walker 1997).

**Social network metrics** – The work on social networks has led to a variety of tools and concepts to analyze the structure of a social network. At a lower level, the network generally is represented as an N X N matrix where N is the number of members in the network and an element of that matrix represents the linkage (possibly weighted to indicate the intensity of the link) between the two corresponding points. A commonly used tool to present that information is the socio-gram which is a network graph showing each member of the network and their links with each others’ . This graph can also be displayed using multi-dimensional scaling (MDS) : a data-reduction technique that tries to maintain the distance between the N points (as indicated in the matrix) in a 2-dimensional plot.

In addition to these display techniques, several other concepts are used (Baker 1992):

- **Sub-group cohesion** – Sub-group cohesion refers to the identification within the network of sub-groups of nodes that have strong ties among them. These sub-groups are sometimes referred to as cliques.

- **Structural equivalence** – Structural equivalence of any two nodes in the network refers to the fact that these nodes present a similar profile of ties. In other words, two nodes are structurally equivalent if they relate to the other actors in the network in the same way.

- **Centrality** – Centrality is a measure that comes in many variants and tries to describe how central a particular player is within the network (Freeman 1979). This metric will be further developed as we talk about organizational networks.
2.2.2. Inter-organizational networks

The central premise underlying the extensive literature on inter-organizational networks is that the conduct and profitability of a firm are greatly impacted by the network in which the firm is embedded. More specifically, the organization should be seen beyond its traditional boundaries, as an integral part of a larger virtual organization in which it is embedded through its multiple alliances. Its patterns of relationships are important; patterns of relationships of other members in that network are equally important. Through its network of relationships, the firm has now extended its reach as it can access a new set of resources with low transactional costs (Gulati 2000). In that sense, the network surrounding the firm can be viewed as an asset of a particular type, a social capital: this asset needs to be carefully built through selected alliances and cultivated with trust. This aspect emphasizes again how important the nature and maturity of the alliances are in characterizing the overall network capabilities. Along with the benefits resulting from access to new resources, the position within a network implies a set of constraints: ties with certain firms might preclude ties with other firms and industries. Similarly, a network might lock a firm into a set of unproductive relationships (Gulati 2000).

Among the several main threads of investigation in that area one of particular interest to us focuses on the benefits of being centrally located within an industry network (Walker 1988, Hagedoorn 1994, Soh 2003). Two variants of that measure are centrality degree and centrality betweenness.

Centrality degree – Centrality degree assesses the number of organizations to which the focal organization is tied. For obvious reasons, this simple metric is of rather limited use as it does not provide a good measure of the positioning within the network: if an organization connects actors that are already linked, its “centrality” role is rather limited. The centrality betweenness tries to overcome this limitation.

Centrality betweenness – Centrality betweenness is a measure of how many times a particular actor lies on the shortest path between two other actors. This measure has been shown to be
superior to other centrality metrics to provide a measure of an actor’s power in that network (Freeman 1979). Walker (1988) suggests that centrality can be a good indicator of the following traits:

- **Unique expertise** – The central actor can possibly be the owner of some niche expertise that makes it central to the rest of the actors in that network.

- **Access to information** – Through its unique position in the network, a central actor has early access to information; it can anticipate technological and market changes sooner than other members in the network.

- **Potential broker** – Finally, a firm in a central position can be well positioned if the network gets decomposed into smaller networks through market forces. It can become a broker between the new sub-networks and might extract value from that new position.

### 2.2.3. Constellations

The concept of *alliance constellation* was introduced by Gomes (Gomes 1996, Gomes 1997) to describe a group of firms linked together by a set of alliances and sharing a common strategic goal. With this view, traditional competition between firms is replaced by competition between constellations where the constellation is the new competitive unit. In that framework, Gomes identifies several key attributes that characterizes the competitiveness of the constellation. Some more structural attributes are the number of firms included in a particular constellation or the underlying structure of the constellation where the structure can vary from centralized to distributed. In essence, the constellation provides flexible capabilities where expertise and assets are specialized and each member of the constellation can have access to those specialized assets without having to internalize the complete value chain (Gomes 1996:40). Each member of the constellation is likely to have links outside the constellation which allows it to manage more effectively the varying needs within the constellation. The combination of those specialized assets and of the alliances provides
ground for synergies as is demonstrated by the Fuji-Xerox case: this joint venture, initially put in place to market Xerox’ products in Asia, ended up developing a small cost-effective copier that became a best seller. This extreme flexibility should be contrasted with the view of the single firm where all assets are tightly integrated but little flexibility is possible. To balance these obvious advantages of a constellation, Gomes (1996) points out that the complexity of governance issues grows significantly with the number of firms within a constellation as their interests are more likely to diverge.

2.3. Rationale for cooperation

Extensive literature has been written on the various rationales that push two firms to reach a cooperative agreement. Some of these rationales are presented here (Contractor 1988, Hagedoorn 1993, Hagedoorn 1994).

Risk reduction – As development projects get larger and technology more complex, the risk associated with potential failure is too significant to be taken on by a single firm and a cooperative agreement is an attractive alternative to reduce the risk factor.

Economy of scale – In many cases, a company might be unwilling to invest heavily in new production assets to support an increased demand and through a cooperative agreement such as outsourcing, production can be transferred to a location were economies of scale can be achieved.

Speed – In today’s fast paced environment being a first mover with a new product or in a new market can be critical. Cooperative agreements can be arranged very quickly to allow prompt access to the necessary assets required to deliver the new product in a timely manner.

Access to technology – Complementarity in technologies is often cited as one of the key rationales for an alliance. It is always costly and difficult for a company to develop a new area of expertise. Through alliances, two companies can join their best complementary skills and create the ground for new breakthrough innovations. A well cited example is the joint venture between Fuji and Xerox which produced a technology well beyond what was initially expected and well beyond what
any single entity could have done alone (Gomes 1996).

**Managing competition** – Cooperative agreements between two competitors can also be used as an effective way to manage competition. While this rationale is rarely acknowledged for obvious regulatory reasons, it has become a reality.

**Getting around regulation** – Regulation can present a major hurdle for a company trying to enter a specific market or to sell a specific product. In this case, allying with a local player can provide a convenient solution.

**Global expansion** – Firms with little global experience are clearly at a disadvantage as they try to reach new geographical markets. New markets require a specific knowledge and expertise that usually takes time to acquire. Cooperative agreements provide in this case an attractive way to reach new territories, leveraging on established distribution channels from the partner company.

**Vertical integration** – Vertical integration refers to the integration of responsibilities along the value chain. Through cooperative agreements, firms can virtually integrate vertically and this will allow them to rip the benefits of vertical integration (better access and control of supplies, closer monitoring of consumer needs) without some of the drawbacks such as increased assets and complexity (Contractor 1988, Miles 1992).

**Dominant design and standards** – In the context of the technology life cycle, an important milestone is the emergence of a dominant design (Utterback 1984). Players controlling that design through specific IP rights (patents) or complementary applications can extract significant benefits by licensing the technology or selling the applications. In promoting a design, the role of alliances can be critical (Gomes 1996). In the age of digital convergence and complex systems, the specification of common interfaces is a required step for the diffusion of some application or technology. Standard alliances provide a forum for companies to work together in defining that standard. A well-known example is the success of the VHS video cassettes format, promoted by Matsushita, JVC and RCA, which became the de-facto standard in spite of a its technical inferiority to the Betamax format promoted by Sony. The role of relationships in the establishment of
standards is further stressed by Gower and Cusumano (Gower 2002) who list the relationships with complementors as one of the four key aspects in building platform leadership.

**Legitimacy** – In some cases, a small company might greatly benefit from a partnership with a well-established player in the field. Such agreement typically goes a long way in giving to the new player more credibility and legitimacy (Teece 1986).

**Customer intimacy** – Access to customer feedback has in many cases proven invaluable for companies trying to further capture a particular market segment. Von Hippel (Von Hippel 1988) further emphasizes the role some lead users can play in identifying new extensions to existing products. He has shown that in the area of scientific instruments as much as 77% of the innovations were developed by users. Given that medical imaging equipment has been used extensively as scientific instruments in the context of research projects, this statistic is of particular relevance to us. As we shall see later, this trend has translated in the medical imaging industry into new relationships between equipment suppliers, hospitals and research centers.

In this section we have reviewed rationale for cooperative relationships. A specific cooperative relationship usually draws from a combination of reasons, some weights more heavily than others depending on the context.

### 2.4. Strategic Views

After a brief review of key rationales for cooperation, we now take a more strategic view at alliances and alliance networks.

**Asset complementarity** – One important view centers on the notion of complementary assets. Complementary assets are those assets that are critical for bringing to market a particular product (production, distribution, applications, etc.). The role of those complementary assets is particularly critical for new technological innovation when appropriability (ability to capture value from the innovation) is low the firm has not access to those assets (Teece 1986). Teece distinguishes three main types of assets: *generalized assets* that are typically always available in an industry;
specialized assets where there is a unilateral dependence between the new product and the complementary asset; finally, co-specialized assets where there is bilateral dependence. Collaborative agreements provide a convenient way to access those complementary assets and the selection of the appropriate mode of collaboration should mainly be driven by the type of assets a firm is trying to access. EMI provides a good example of a company that had developed CAT scanning technology well ahead of its competitors but failed to capitalize on that advantage: the new devices required extensive training and servicing and EMI did not leverage on a partnership.

Technology centric views – Roberts (1985) presents a useful framework to select the appropriate type of relationship to establish when trying to acquire a technology. The centerpiece of this framework is the familiarity matrix which includes the familiarity with the technology a firm is trying to acquire and the familiarity with the market it is trying to enter. For each quadrant of that matrix, optimum entry strategies are proposed, including internal development or straight acquisitions. It also proposes various paths of evolution for the various options chosen.

Another important view centers on the maturity of the technology of the firm seeking a collaborative agreement. Using the technology life cycle (Utterback 1984) the technology can be in one of the four phases: fluid, transitional, mature and discontinuities. For each phase, certain types of alliances dominate (Roberts 2001).

The value chain strategy framework – This framework (Fine 2002) centers on the sourcing decision or in other words the “make versus buy” question.

At a strategic level, every sourcing decision throughout the value chain is a choice between dependence and independence for supply and knowledge (Fine 2002)

In this framework, Fine combines a well known quantitative model (Economic Value Added or EVA) with a qualitative model (Strategic Value Added or SVA) as the basis for evaluating sourcing decision. The SVA which provides a simple mechanism to assess the level of dependence to the supplier relies on five key components: the importance the customer gives to the particular component, the rate of change in the underlying technology or the clock-speed (Fine 1998), the
competitor’s position, the availability of many suppliers, and the modularity of the architecture.

While these quantities are useful for assessing sourcing decisions, they can also provide good insights in how to look at alliances. Ultimately, the competitive advantage of a firm resides in its ability to evaluate those tradeoffs and to design its value chain in the most advantageous way: “make or buy” is a core competency (Fine 1996).

Table 2: Optimum entry and evolution strategy to new markets.

Co-opetition view – No single word symbolizes more effectively the level of ambiguity implicit in most alliances than co-opetition, a term coined by Ray Noorda from Novell (Brandenburger 1996). The strategic framework centers here on the balance between competition and cooperation, balance
that should to be maintained along two main axes: its relationship with suppliers and customers, and its relationships with competitors and complementors. Recognizing the symmetries of those relationships is at the core of the value-net model proposed by Brandenburger (1996). In many cases, the same firm qualifies as a complementor in that it contributes in creating a market for products or services, while at the same time acts as a competitor in the sense that the market is shared by the companies. As an example, Siemens has an agreement with one of its competitors, Kodak, to offer as part of its product suite Kodak’s Computed Radiography system.

2.5. A Dynamic View

We have so far focused on a static view of inter-organizational networks. This view is restrictive as we plan ultimately to examine the dynamics of a particular industry. We present here two dynamic models, the double helix model and the network dynamics model.
The double helix – The double helix was proposed by Fine to model the evolution of an industry. According to this model, industries go through two alternate cycles (double helix) where they oscillate between vertical integration and horizontal disintegration. Fine identifies a set of disintegration forces (niche competitors, product complexity, organization rigidities) and a set of integration forces (technical advances, supplier market power) that come into play in each of the cycles. In the context of the inter-organizational network, these forces can be viewed as playing an important role in shaping alliances between various players and their evolution over time.

In his thesis on the telecommunications industry Kawashima expands on a combination of these concepts and introduces a simple analysis framework used to describe the dynamics of the telecommunication industry as it faces the challenge of the IP technology (Kawashima 2002). For his analysis, three separate value chains were introduced – i.e. one for design, one for supply and one for management. Within each value chain, the central actor acts as an integrator and is associated with the letter I in Figure 2: each value chain includes the actors (four actors in total) and linked either tightly (thick connections) or loosely (thin connections). While this view is void of any reference to networks, it introduces a powerful concept with a multi-layer view of parallel value chains.

![Value Chain Analysis Framework proposed by Kawashima (2002)](image)

Figure 2: Value Chain Analysis Framework proposed by Kawashima (2002)
As pointed out earlier, one of the main perceived drivers for the increase in alliance formation has been the increased pressure to deploy new products or applications in the shortest amount of time. In that respect the concept of clock speed (Fine 1998), introduced to characterize the rate of change of a particular industry, is quite relevant. More specifically Fine suggests three different clock speeds (product, process and organizational) and a variety of ways to measure them. As an example, a good proxy for the product clock speed can be the rate at which new products are released. In the context of a network of competence, this concept of clock speed is critical since it dictates the pace in which various players in a network evolve: it is not difficult to imagine that as two players with different clock speeds try to build a relationship, issues related to expectations and culture might arise. It is worth noting that while this concept is important, relatively little quantitative data on clock speeds for specific industries is available.

Network dynamics – Leveraging on the framework of inter-organizational networks discussed earlier, Madhavan (Madhavan 1998) addresses specifically the question of how these networks vary over time. Mandhavan argues that networks evolve in response to key industry events in a manner that either reinforces or loosens the structure (structure re-enforcing event and structure loosening event). In his analysis, centrality and the relationship between blocks of firms are used as one of the primary metric to measure structural change. Examples of structure re-enforcing events include incremental innovations that further leverage the set of current assets (distribution channels, existing expertise, ...) or regulatory initiatives that require significant resources from established companies. Conversely, structure loosening events include the introduction of disruptive technologies (Christensen 1997) or business models that require radically new partners and favor peripheral firms. It is important to point to make that large, established, and companies can be effective in managing structure loosening events to the extent that they can leverage their extensive network to dampen the shock.
3. The Medical Diagnostic Imaging Industry

Diagnostic imaging refers to all imaging techniques allowing physicians to visualize in a non-invasive way internal structures in order to come up with a diagnosis for an injury or to determine the nature, location and size of a disease. Diagnostic imaging is now a major component of the medical process.

This field, with a history of more than 100 years, has been the ground for many innovations. Diagnostic imaging is a sub-field of medical imaging and while we might refer to developments in the medical imaging field to the extent that they spill over to other fields, our focus is on the diagnostic segment. In addition, as the distribution and service networks tend to be defined within national boundaries (Mitchell 1992) the study is limited to the US market.

Following a brief history of this industry, we will highlight its main characteristics. Finally we will describe the current environment and some key trends.

3.1. A Brief History

The field of medical diagnostic imaging emerged in 1895 with the discovery of X-rays by Roentgen. With this technique, images were created by recording on film the level of absorption of short waves of radiation passing through parts of the body. Commercialized shortly after, x-ray became the main tool used by doctors to see inside their patients. While the technology improved over the following 60 years with the introduction of better films and monitors, the improvements were very much incremental and the images remained dim. In the 1960s the field expanded significantly. Computers were linked to both old and new sources of data resulting in the appearance of multiple subfields. Nuclear imaging, a technique that maps the concentration of a previously ingested radio-active substance (tracer), was introduced in 1959 in the clinical environment and has been extensively used for functional imaging. The year 1963 marks the introduction of the first computerized device, the ultrasound: during an ultrasound examination, a manual device containing
a piezo-electric transducer generates sound waves reflected by the organs in the body. The reflected sound waves were in turn converted to electrical signals that were fed into a computer and “assembled” to produce an image. Since this technique did not involve any radiation, it allowed the visualization in real time of many organs that could previously not be studied. Ten years later, in 1973, the first computed tomography (CT) scanner was installed in a hospital. CT used a rotating X-ray device to generate cross-sectional images that were re-combined by a computer into a detailed image of a clarity never seen before. The main drawback of this technique was the time required by the procedure.

Finally the 1980s saw the appearance of nuclear magnetic resonance imaging (MRI) and many new modalities. MRI relies on a strong magnetic field and on the interference of this field to generate images. Newer modalities include digital radiography (1981), a digital version of the traditional X-ray machines, positron emission tomography (PET).

An important development taking place in the late 1990s has been the development of Picture Archiving and Communication Systems (PACS). These systems address many of the storage and management needs faced by hospitals by providing a unified way to store and retrieve medical images in a digital format. The main result has been the introduction of the DICOM standard that allows seamless communications between the various devices. This trend has been accentuated by the Health Insurance Portability and Accountability Act (HIPAA) enacted in 1996 to provide continuity of healthcare coverage while reducing inefficiencies.

The role of imaging has gradually evolved from a purely diagnostic tool to a tool that can serve in a unifying way throughout the complete treatment sequence from diagnostic, treatment and recovery. The central idea is that once images have served as a support for the diagnostic of a disease, they can be used to plan and execute the treatment (e.g. guide the surgery) and finally, integrated into the recovery phase where they would be compared with an updated set of images in order to monitor the progress of the recovery. As the accuracy and real time availability of the imaging modalities improve, diagnostic and treatment could eventually merge allowing the doctor to diagnose and treat
during the same procedure, saving the patient the inconvenience of another visit and that of an invasive procedure. For more information on these imaging modalities and their applicability refer to Appendix A.

3.2. Key Market Characteristics

We describe below some of the main characteristics of the diagnostic imaging industry.

**Revenues trends** – In recent years, the US market in medical imaging has been fairly stagnant with revenues neighboring $4.5 billions – about 44% of worldwide revenues. Within that market, the contribution of each imaging modality has gradually shifted. The market of more traditional modalities has saturated and growth resulted mainly from newer modalities such as nuclear medicine and computed tomography (CT) – with a growth in 2001 of 3.1% and 6.9% respectively (DH 2003). It is worth pointing out that the price tag attached with new modalities is significantly higher than that of more traditional modalities, reaching $2-3 million for the imaging device. The breakdown of those revenues according to the five imaging modalities is shown in Figure 3.
High level of innovation – As our brief history overview highlighted, the medical imaging field has been an extremely fertile ground for innovations. The imaging instruments draw from many different knowledge bases. One key reason for the high rate of innovation is the technology advancement in the two core areas of electronics and biology. Another reason is certainly the size of the market which has attracted many companies of various sizes. As a result, the complexity of the devices as well as the rate of evolution of those devices has steadily increased, requiring re-training of personal and extensive hand-holding from device makers (Barley 1990). In an industry characterized by the emergence of numerous technical subfields, incumbents have used alliances extensively to avoid cannibalizing while at the same time managing the risk (Mitchell 1992). A major indication of this commitment to high level of innovation is the high level of investment made by manufacturers, i.e. 9% to 11% of revenues which compares extremely favorably with the
overall industry average of 3% to 4\%².

**High level of uncertainty** – The rapid rate of introduction of new technologies has contributed to a high level of uncertainty in the diagnostic imaging area. But two other factors have significantly compounded this problem: regulation and reimbursement issues.

- **Regulations** – Medical devices in the US have been regulated by the Food and Drug Administration (FDA). Under the amendments passed in 1976 manufacturers of medical devices must insure safety and effectiveness before marketing approval. Medical imaging devices for the most part fall in the Class II type of devices with moderate degree of risks: for these devices, a simplified filing (510k filing) is available to the extent that the device is similar enough to a product already on the market. For new techniques, more extensive filing is required, raising the cost and uncertainty in the road to market.

- **Reimbursement** – On the reimbursement side, the profitability of certain procedures has been driven by whether the procedure is reimbursed by insurances and Medicare / Medicaid agency and by the amount of the reimbursement by insurances. With the push to reduce overall healthcare costs with managed care, certain procedures are simply not reimbursed if they are not deemed cost effective³.

Both issues of regulation and reimbursements are at the mercy of major macro-economic indicators.

**Complementary assets are critical** – Given the typical high investment cost of medical imaging systems and the increasing complexity of the systems, the role of complementary assets such as brand, training and technical support has been critical. As a result, major brands find themselves in an increasingly dominant position.

- **Low appropriability** – While various forms of IP protection such as patents and copyrights

² Standard & Poor’s Industry Surveys – Healthcare: Products & Supplies, March 2004
³ Standard & Poor’s Industry Surveys – Healthcare: Products & Supplies, March 2004
are in place and used in the diagnostic imaging field, appropriability is low due to the fact that new features are easily imitable by competing firms (Mitchell 1989). This fact puts significant emphasis on the role of complementary asset to secure a good rent from the innovations (Teece 1996).

- **Clinical trials** – The need for clinical trials has limited the ability of small companies to embark on the development and approval of a new device single handedly.

- **High service levels** – The rapid rate of innovation has translated into necessary, frequent retraining and upgrades – around one third of revenues come from after sales service and upgrades⁴ - and good serviceability has been a key decision factor for hospitals (Mitchell 1989). A related point is that due to overall cost and legacy systems, supporting assets retain their value (Mitchell 1992).

- **Emphasis on low cost of ownership** – Another driver has been the push for medical institutions to reduce the number of vendors they interact with. As a result, most vendors have been trying to provide full solutions, going as far as offering to service systems from competitors: in 1994, GE announced a multi-vendor program and other equipment suppliers have followed GE’s lead (DB 2003). As a result, the current system has favored incumbents with an established reputation, well-oiled distribution and service channels, and already installed hardware and software. With the increased of data produced in the hospital environment, improved manageability has also been at the forefront of hospitals IT managers who have to deal with a wide combination of proprietary and commodity hardware and software tools. This has triggered a strong push for the wider adoption of standards and more compatibility between devices. The introduction of the DICOM standard in the context of PACS is one manifestation of that trend.
Multiple customer segments – Another important characteristic of this market is that it caters to different customer segments. X-Ray, nuclear imaging, CT, MRI systems are typically used by hospital-based radiologists. On the other hand, ultrasound systems are sold to specialists in hospitals and private practices. In that sense working closely with the customer has become a critical component of the further development of diagnostic imaging systems. An example is the important role played by the University of Pittsburgh in 1999 to develop the combined CT and PET scanner by the CPS, the joint venture between Siemens and CTI.

Improved quality of service – As in many other industries, the expectation of the public has been the continuously improved quality of care. That has translated into the expectation that medical data can be accessed by doctors from anywhere, even in a mobile environment. Similarly, many hospitals have started mandating 24/7 radiology coverage. As a result, radiology centers affiliated to US hospitals have opened in different time zones. As an example, Massachusetts General Hospital has opened centers in Australia and India. Finally, it is perceived that imaging can significantly improve the quality of services by alleviating in many instances the need for invasive surgeries – e.g. ultrasound guided intervention have become more common.

US market specificity – Several environmental aspects are specific to the US market. The aging of the US population is one of the most significant trends what will affect the industry. The Census Bureau estimates that by 2020 the population over 65 will reach 17% of total US population, up from 12.4% in 2000; in 2000, this market segment accounted for 40% of the expenditures⁴. In addition to further stressing the Medicare and Medicaid budget, one of the major implications is that significant amount of resources will be dedicated to addressing diseases and treatments affecting this age group.

Globalization – While the diagnostic imaging market is characterized by considerable local

⁴ Market Category B: Medical Devices 2003

⁵ Standard & Poor’s Industry Surveys – Healthcare: Products & Supplies, March 2004
specificity, there are also some major global trends. First, the key industry players are large global companies with research, development and manufacturing facilities spread around the world. Secondly, the introduction of the internet along with a secure standard to access diagnostic images remotely has contributed in further blurring the national boundaries. As a result, remote examination of medical images has become a reality and this option is increasingly used to cope with the push for 24 by 7 coverage for radiology services and the shortage of radiologists. An example is the outsourcing by a major Boston-based hospital of radiologist readings to Australia and India.

**Trend towards consolidation** – The last ten years has seen a steady trend towards consolation in the medical technology industry (Go 2003). This trend has been favored by the confluence of several factors already mentioned. Complementary assets such as brand and distribution networks are more important: accessing the regional markets require significant resources and the hospitals and medical imaging centers usually avoid buying from small companies when they are purchasing million dollar equipments. Furthermore, larger players have looked at merger and acquisitions as a way to leverage on their large asset base to further generate growth at a time when overall revenues are stagnating. As a result a total of six companies in the world have emerged as full line companies offering the complete range of products in the imaging area, from ultrasound systems to MRI systems and PACS.

In summary, the high level of uncertainty due to the multi-disciplinary character of the industry provides a very fertile ground for alliances. To confirm that, incumbents or industry leaders have been shown to leverage on alliances to enter new technological subfields, especially when firms’ core products are threatened (Mitchell 1989); while they have less incentive to invest in innovation

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7 These companies are GE, Hitachi, Philips, Shimadzu and Toshiba.
as it may damage earlier investments and result in the cannibalization of their revenues (Mitchell 1992), they cannot wait too long before ramping technical expertise. In another example, EMI’s lack of alliances has been identified as one of the reason why they were unable to access complementary assets needed reap significant returns for their unique CT scan technology (Teece 1986).

### 3.2.1. Technology trends

In the medical diagnostics area several key technical trends can be identified.

**Going to digital** – As the newer imaging modalities are gradually taking over and digital substitutes for traditional analog modalities such as X-ray are becoming available, the move toward a completely digital environment has become a reality. New regulations (e.g. HIPAA) that try to address the difficulty in transferring records from one healthcare provider to another have provided an additional push by forcing the industry to reduce the paperwork and by trying to establish common standards. The most significant outcome has been the development of Picture Archiving and Communication Systems (PACS) that rely on a common standard (DICOM). Overall adoption of digital technology has been slower than anticipated due to the high upfront cost of the equipment and the current large installed base of non-digital equipment (X-rays). As an example, the penetration of PACS equipment remains low at 15%-20% (DH 2003).

**Faster and better** – This trend captures key incremental innovations made across all the imaging modalities. These innovations have to a large extent leveraged on the improvements in computing and components miniaturization. As a result, imaging techniques have become faster and the associated devices smaller, resulting in improved image resolution. As an example, the introduction of slip-rings to power the tube and the many rows of detectors for CT scanners has allowed significantly faster scan time, down to 15 to 20 seconds for the whole body. This has resulted in improved image quality, as the patient is more likely to not move during the procedure and higher productivity (return on investments). In the MR area, smaller and shorter magnets are now being
used which has significantly improved the acceptance by patients who have traditionally dreaded the claustrophobic sensation associated with the procedure. Finally, the reduced time and increased resolution has opened up new opportunities for medical imaging.

**Fusion of traditional modalities** – A more recent technological trend has been the fusion of imaging modalities. This trend has allowed the emergence of new techniques that combine the benefits of the underlying technologies. A particularly interesting example is the combination of PET and CT that was demonstrated in 1999 at the University of Pittsburgh. This technology, resulting from a joint venture between Siemens and CTI, provides improved diagnostic capabilities by allowing the examiner to view both physical and chemical information simultaneously.

**Use of contrasts agents** – While the use of contrast agents could fall in the category of “technology fusion” this trend has gained so much importance that it warrants its own entry. Contrast agents are now used in combination with all five major imaging modalities to produce higher resolution images and monitor more accurately the functioning of certain organs. Under that general category, *molecular imaging* has attracted particular attention. Molecular imaging combines the traditional imaging modalities with contrast agents that adhere to special molecules to monitor biological processes in living organism (in vivo) at the molecular and cellular level. While in its infancy, molecular imaging has the potential to become the method of choice for measuring biomarkers (see Glossary). As an example Epix and Schering announced the discovery of a contrast agent that can be used with MRI to diagnose vascular disease. This contrast agent, currently waiting for FDA approval, could replace coronary X-ray angiography, a highly invasive technique.

**Personalized medicine** – Personalized medicine refers to the use of a variety of techniques in order to better tailor the treatment to a particular individual. This would allow not only better dosage but also fewer side effects. Imaging modalities could play a major role in personalized medicine by allowing better monitoring of the treatment. The implications of this approach are significant. Medications with major benefits to many patients are currently withdrawn from the market if they cause adverse side effects to some patients. Assuming that we could identify effectively the
segment of patients who would not respond well to the treatment, these medications could have a new life.

**Specific clinical areas** – The area of cardiovascular diagnostic imaging is an area of intense interest. Coronary heart disease remains the leading cause of mortality in the US, accounting for about 39% of the deaths in 2001. The estimated cost is around $370 billion, broken down between 43% in indirect costs and the rest in direct costs⁸. This provides an attractive opportunity for diagnostic imaging vendor as an estimated 7 million patients are the subjects of cardiovascular related diagnostic every year. However diagnostic imaging techniques in that area remain quite ineffective, costly and invasive: coronary X-ray angiography, one of the definite diagnostic procedures, combines the use of X-ray with an iodinated contrast injected in a surgical manner. Therefore, significant resources are invested to further improve the attractiveness and the efficiency of those techniques. One recent development that has attracted significant interest is the use of MRI with contrast agents that bind to particular proteins. Such contrast agent, MS-325, has been introduced by Epix and is currently waiting for FDA approval.

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⁸ American Heart Association
3.3. Industry Attractiveness

To conclude our assessment of the medical imaging industry, we review the industry attractiveness using Porter’s five forces (Porter 1985). We should keep in mind that this industry combines several different sub-industries. A summary of our main points is presented in Figure 4.

**Threats of new entrants** – The threat of new entrants is low as large capital investments are required for high-end imaging equipment. In addition the highly advanced technology and know-how required is also a limiting factor; new entrants need skilled resources and technical knowledge. Finally, IP protection serves as a barrier to entry but getting around that barrier is fairly easy. In contrast, barriers to entry are low for less expensive devices (such as ultrasound) and they are becoming commodities.

**Bargaining power of suppliers** – The bargaining power of the suppliers is relatively low given the large number of potential technology and component suppliers. Suppliers can play a major role if they control the desirable technology. However, in many cases, their ability to switch from a customer to another is limited as their technology or component is customized for a particular customer. Overall, their ability to forward integrate is rather limited given the capital investments required. Conversely, the propensity of firms in the industry to backward integrate is very high.

**Bargaining power of buyers** – The bargaining power of the buyers is moderately high given that the array of products offered in medical imaging is proposed by several vendors. However, once a hospital has made a commitment to a particular vendor, its ability to switch is lower: new vendors necessitate retraining of the personnel and in many cases, reintegration into the existing infrastructure given that many of the devices are not entirely interchangeable.
Figure 4: Porter’s five forces for the medical imaging industry
**Threat of substitute products or services** – The threat of substitute products or services is rather low. Medical imaging is now the standard for diagnosing certain diseases and conditions. The main threat of substitute comes from within the industry, with one type of modality potentially replacing another one as the technology improves.

### 3.4. Overview of Incumbents

For the present study we shall concentrate on the four main players in the US market, i.e. GE, Siemens, Philips and Kodak. As we shall see, over the last 5-10 years, through alliances and acquisitions, all four companies have become dominant players in the US market.

**GE** – GE Healthcare (formally GE Medical Systems) is a leader in medical diagnostics, monitoring equipment and services. With revenues in 2003 over $11 billion it is one of the major players in the medical imaging area. GE Healthcare is broken down in two business units:

- GE Healthcare Technologies (around $7.5 billion) focused on the diagnostic technologies and information technologies and the integration of those technologies across the enterprise.
- GE Healthcare Bio-sciences (around $3.5 billion) focused on diagnostics, drug discovery and protein separation systems

This recent reorganization signals the strong emphasis GE has put on life science. Its acquisition of Amersham in 2003 was a leading indicator of that trend.

At the product level, GE is a technology driven company and its offering is very complete, including all traditional imaging modalities but also Electron Beam Tomography, combined PET / CT scanner developed in 2001. GE also has a strong financing arm – GE Healthcare Financing Solutions.
Siemens – Siemens Medical Solutions is one of the largest suppliers of medical devices with revenues around Euro 7.4 billion in 2003. Siemens MS is renowned for its innovative products, complete solutions and services in the areas of diagnostics, therapy products and information technologies. In the medical imaging field Siemens offers a complete set of solutions with the minor exception of CR which is provided as part of an alliance with Fuji and Kodak. Siemens is above all an engineering driven company with a strong focus on innovation and internal development. Among its major innovations they demonstrated the first digital networking system for an X-ray department in 1992. In 1999, they demonstrated a combined PET/CT imaging system that produced a single image. Their recent emphasis has been on improving the work flow by providing integrated solution that span the complete cycle, from diagnosis to treatment and recovery. In contrast to its competitors Siemens has made very few acquisitions in recent years, with the exception of Acuson purchased in 2001 for their ultrasound capabilities.

Philips Medical Systems – Philips Medical Systems (MS), a subsidiary of Philips, is one of the major suppliers of medical imaging equipment and systems. As a whole, Philips MS reported revenues slightly under € 6 billion which accounts for around 20% of Philips overall revenues. Within Medical Systems the imaging component accounts for slightly over 50% of revenues. Over the last five years Philips has invested significant resources to acquire companies and build a fairly complete portfolio of products. As an example, the acquisition of ATL in 1998 was largely driven by the need to complement their ultrasound offering. More recently, Philips has been making inroads in the healthcare IT arena by forming a partnership with Epic. In line with other major players in the industry, Philips offers financing service with its Philips Medical Capital arm.

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9 From the presentation of Professor Claus Weyrich, head of Corporate Technology at Siemens AG. On “Innovation management at Siemens”, Sloan School, February 24, 2004.

10 Philips 2002 Annual Report
**Kodak** – As opposed to the first three companies presented so far, Kodak is not the typical medical imaging company with a full product line. Kodak is a well known provider of products and services for the capture, processing, distribution, and printing of images covering both the diagnostic and non-diagnostic domains. In fact Kodak involvement with medical imaging dates to 1896 when the company announced the first product for the capture of images created by the newly discovered X-rays. More recently Kodak has focused on Digital Radiography, the digital replacement of X-ray devices, and PACS systems. By the end of 2003, Kodak’s Health Imaging Group accounted for $2.4 billions in revenue worldwide out of which around $1 billion was generated in the US market.
4. Framework

Leveraging on several of the tools presented in the literature review we will now focus on building the industry network. This network will provide the underlying framework to answer the following two questions:

1. To what extent a network centric framework can provide an accurate view of the diagnostic medical imaging ecosystem? Can it help identify “key” actors and their attributes?

2. Can this network centric view help identify some of the industry dynamics? Does it help detect shifts in network locus and what do those shifts mean?

To answer the first question, we shall examine the alliances and acquisitions that have taken place in the last 15 years and create a visual representation of the industry network. Our approach will start with a high level view of either broad industry groups or industry sub-groups. Through this initial grouping in industry sub-groups, we can create a network of sub-industries in the medical imaging area. By analyzing the central players in that network, we expect to identify sub-industries that play a central role. To answer the question on the specific benefits these central players get, we have asked experts in the medical imaging field to provide an assessment of their relative positioning within the industry.

Another dimension of investigation focuses on the dynamics of those sub-industry networks. By examining the shift in centrality over all three time periods, we shall highlight some of the dynamic trends in that industry. Finally, we shall focus on the four incumbents we have chosen and we shall examine their relative positioning within that network. This analysis will be the basis for the next section where we provide an overall assessment of the trends in that industry from a network centric view.
4.1. The Data

The first step in data gathering was to compile a list of alliances and acquisitions concluded since the early 1980s. To compile this list of transactions, we relied exclusively on the Recap\textsuperscript{11} database and on press releases from the Factiva database. Our list includes a total of 343 transactions involving 306 companies. For each transaction we include the name of the two partners and a brief description of the purposes of the alliance. In many cases, multiple purposes are listed for an alliance with the ordering reflecting the relative importance of each purpose. Finally, to depict the dynamics in the industry over time, the original time period was divided into three intervals: 1980-1989, 1990-1999 and 2000-2003.

4.1.1. Caveat

Before we embark on the analysis of the data collected it is important to point out some of the intrinsic limitations of these data, many of which have been highlighted in the literature (Hagedoorn 1994):

- Alliances are typically loosely defined agreements that are often not reported officially for strategic or legal reasons. These agreements can also be informal and undocumented. This means that the data included here is partially complete.

- On the flip side, the announcement of alliances does not necessarily imply an active relationship. As we discussed earlier, alliances can be used to deter a possible competitor rather than to actually engage in a long-term relationship.

- Dissolutions of an agreement are rarely tracked in the press. This means that we have in fact little ability to know whether a particular agreement is still in place a few years after its initial announcement, short of reviewing the annual reports of both firms involved.

\textsuperscript{11} Recombinant Capital (Recap) is a consulting firm specializing in biotechnology alliances, earned alliance revenues, product sales, employment agreements, companies information and capitalization.
Finally, the press may have some bias in reporting alliances in “trendy” industries. This bias would result in alliances appearing in bursts.

4.1.2. The players

The first stage of the analysis focused on the players in the medical imaging ecosystem. From our initial list of 306 companies we eliminated firms that were not linked to the core inter-organizational network as we are primarily focusing on the network developed around our four incumbents. This filtering reduced the number of firms to 212. Each firm was then categorized in its industry sub-group: the categorization process was primarily based on the industry classification provided by the Hoovers database. If a firm covered several industry sub-groups, the one that was most relevant to medical imaging was retained. A total of 28 industry sub-groups were identified in addition to the incumbent category. The industry sub-groups were then further grouped in 11 broad categories. The list of industry sub-groups and broad categories are presented in Table 3. For each broad category and sub-industry, we include the percentage of the 212 firms falling into that category.

<table>
<thead>
<tr>
<th>Broad Category</th>
<th>Code</th>
<th>Percent of Firms in Broad Category</th>
<th>Industry Sub-group Description</th>
<th>Code</th>
<th>Percent of Firms in Industry Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incumbent</td>
<td>INC</td>
<td>1.9%</td>
<td>Medical imaging incumbents - Includes GE, Siemens, Philips and Kodak</td>
<td>GE, SIE, PHI, KOD</td>
<td>1.9%</td>
</tr>
<tr>
<td>Medical Equipment</td>
<td>MED</td>
<td>22.7%</td>
<td>Medical devices – A firm developing medical imaging devices such as transducers.</td>
<td>med</td>
<td>4.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medical equipment – A firm developing medical imaging equipment such as ultrasound or MRI systems.</td>
<td>mie</td>
<td>18.0%</td>
</tr>
<tr>
<td>Pharmaceuticals/Chemicals</td>
<td>PHA</td>
<td>29.4%</td>
<td>Pharmaceuticals – Traditional large pharmaceutical companies</td>
<td>pha</td>
<td>8.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pharmaceuticals biopharma – Small pharmaceutical firms focusing on larger molecules than traditional pharmaceutical companies</td>
<td>bph</td>
<td>6.2%</td>
</tr>
<tr>
<td>Category</td>
<td>Code</td>
<td>Percentage</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>------------------------</td>
<td>------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>dgs</td>
<td>12.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>diagnostic substance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pharmaceutical companies selling diagnostic substances.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemicals</td>
<td>chm</td>
<td>2.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotechnology firm</td>
<td>bio</td>
<td>1.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional large</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biotechnology firm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotechnology research equipment</td>
<td>bre</td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm involved in the development research equipment for biotechnology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotechnology services</td>
<td>bts</td>
<td>0.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm providing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biotechnology services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imaging Software</td>
<td>isw</td>
<td>7.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imaging software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm developing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>imaging software such as 3D and 4D visualization tools or computer aided diagnostic (CAD) tools.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td>sft</td>
<td>4.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm developing general purpose software such as networking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software archival</td>
<td>swa</td>
<td>0.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm developing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>software used for general archival and archival of images.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthcare software</td>
<td>hs</td>
<td>1.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm developing and selling software for healthcare management.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Components</td>
<td>cmp</td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer hardware</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm selling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>computer hardware</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imaging equipment</td>
<td>img</td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>general purpose imaging equipment such as displays.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical components</td>
<td>mec</td>
<td>0.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and selling mechanical components such as magnets.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware components</td>
<td>hard</td>
<td>6.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and selling hardware</td>
<td></td>
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<td></td>
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<tr>
<td>components such as DSP cards, storage devices.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Services</td>
<td>it</td>
<td>0.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm offering IT services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer services</td>
<td>cps</td>
<td>0.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm offering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>services for computers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical services</td>
<td>ser</td>
<td>3.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A firm providing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>medical specific services such as diagnostic imaging services, purchasing, billing, tele-radiology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical lab</td>
<td>lab</td>
<td>1.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical laboratories</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>that perform exams</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Table 3: Classification of firms in the inter-organizational network into broad categories and industry sub-group based on Hoovers primary industry label, along with the percentage.

Careful analysis of the table calls for a couple of comments. First, the diversity of the sub-groups illustrate the highly multi-disciplinary aspect of the industry – in fact, medical devices and medical equipment companies account for less than 25% of the 212 firms. Second, the percentage of pharmaceutical or pharmaceutical related companies (categories pha, bph and dgs) is high – this broad category accounts for almost 30% of the 212 firms.

4.1.3. Alliances and acquisitions

Alliances and acquisitions determine the links in our network. These relationships are classified into a combination of 28 types of relationships presented in Table 6 (Appendix B – Alliance types and their description). Out of those 28 types of relationships, 26 were drawn from types defined in the Recap database. The two additional relationship types, labeled “lead deployment alliance” and “compatibility alliance”, were added to reflect some more specific relationships common in the medical imaging industry that fall outside the scope of our initial list.

- **Lead deployment** – In a lead deployment alliance, an agreement is reached between a manufacturer and an organization that uses the device. The manufacturer provides some of the equipment (usually from most advanced product line) to the organization at a discount

48
price. In return, the organization (a research facility or a hospital) accepts to work closely with the manufacturer to provide feedback on the product and on how to further improve it. This trend is consistent with many studies emphasizing the critical role played by advanced or lead users in coming up with innovations (Von Hippel 1988). In the medical imaging area, lead users can be found in universities, research institutes or hospital with research facilities – where they can modify (to the extent allowed by the manufacturer) the existing equipment in the process of their experimentations. As an example vendors of imaging equipment have allowed researchers to modify the physical and software configuration of MRI machines by releasing the safety interlocks and by letting users adjust the positioning of the magnetic coils. This approach seems to have been extensively used by vendors such as GE who reported informally that many innovations resulted from observing users modify the configuration of MRI machines\textsuperscript{12}.

- **Compatibility alliance** – This type of alliances is common between manufacturers in the medical imaging arena. In those agreements, two device manufacturers agree to work together to insure that their respective products can interface with each other. In many cases, these agreements are forced upon on vendors by hospitals and health care providers who want the ability to mix and match best-of-breed products from different vendors.

### 4.2. Industry Sub-groups Analysis

In the first part of this analysis, we focus on the industry sub-groups defined in Table 3. The goal is to point out structural trends that may provide some insights in the industry.

#### 4.2.1. Broad Trends between 1980-2003

In our initial analysis of the dynamics in the medical imaging industry, we look at trends in alliances and at industry groups over the three time periods defined earlier. For the trends in types

\textsuperscript{12} Based on a discussion with Professor von Hippel.
of alliances and acquisitions, the numbers are normalized on a yearly basis to allow comparison and presented in Figure 5. A couple of points can be made:

- Given the low number of acquisitions and alliances in the first period (1980-1989), the statistical significance of any metric used during that period should be treated with caution.

- We notice a steady increase in the average number of alliances and acquisitions raising from under 5 per year in the 80s to over 15 in the 90s, and to over 30 in the early 2000. This trend is consistent with the trends reported in the Information Technology and the Biotechnology (Hagedoorn 1993, Barley 1992) industries.

- As a percentage of all transactions reported, acquisitions steadily increased to reach 14% of the transactions in the 2000-2003 period. This trend toward consolidation has already been mentioned as an important characteristic of that industry.

- Another interesting set of trends is the steady decrease in licenses, joint ventures and R&D alliances in favor of distribution agreements. It should be noted however that in absolute terms, licenses, joint ventures and R&D alliances have either remained constant or slightly increased. This would indicate that the overall increasing trend in alliances is driven to a large extent by the rise in distribution alliances.

- A final interesting point is the seemingly sudden increase in lead deployment alliances in the 2000-2003 period. As discussed earlier, this type of alliances are put in place to allow manufacturers to leverage on some advanced groups of users to further improve their devices. We believe that this increase is not meaningful since it is well established that these alliances have been widespread in the industry for many years. Most likely this type of alliances was simply not properly reported in the past.
Figure 5: Trends in alliances and acquisitions in the 1980-2003 period.
4.2.2. Players' alliance participation

On Figure 6, we evaluated for each time period the fraction of firms participating in alliances and acquisitions in each broad industry category as defined in Table 3. The purpose here is to identify industry sectors that have potentially taken an active role in the acquisition / alliance processes.

![Bar chart showing the mix of alliance and acquisition partners in terms of broad industry categories over the 3 time periods.]

Figure 6: Mix of alliance and acquisition partners in terms of broad industry categories over the 3 time periods.

Figure 6 allows us to make the following observations:

- Over the 3 time periods studied, the mix of partners has significantly diversified. One interpretation is that, as the industry matured new industry segments have played a more important role in both innovation and commercialization processes.

- The second observation is that incumbents have taken a relatively greater role in the later time period than in the 1990-1999 time period. This trend is consistent with the increased number of acquisitions and with the consolidation in the industry. As far as the first time period is concerned, the data seems also to indicate a large proportion of incumbents' involvement but the limited data sample prevents us from drawing any major conclusions.
• Thirdly, the proportional number of alliances or acquisitions involving pharmaceuticals (including biopharmaceuticals and diagnostic substances) and biotechnology firms has been going down consistently in favor of the more traditional medical imaging companies.

• Finally, it is worth pointing out the significant increase in the number of alliances and acquisitions involving service companies. From the 1990-1999 period to the 2000-2003 period, it has grown from less than 1% to more than 5%. Within that industry segment, the increase comes mostly from medical service companies (refer to ser in Table 3) providing a range of services from diagnostic imaging services to billing and tele-radiology. This increase emphasizes again the increasingly active role these companies are playing in the delivery of medical imaging.

4.2.3. Network views

As mentioned earlier, the network view of the industry provides key insights on the medical imaging industry by incorporating some of the structural knowledge. Our network based analysis is broken into two major parts. First we concentrate on visual representations, i.e. a network layout using the MDS technique described earlier. Then we proceed and analyze the centrality measure by analyzing the changes over time for each industry sub-group.

4.2.3.1. MDS display

Multi-dimensional scaling (MDS) is a visualization technique used to display multi-dimensional networks of nodes onto a 2-dimensional plane while trying to maintain the “proximity” between the nodes in the network (Baker 1992). The input for MDS is an N X N matrix for the N nodes in the network and the Nij element in the matrix represents the “weight” of the relationship between i and j. In our case, the weight is given by the frequency of relationships between two nodes, irrespective to the type of relationships. The MDS lay-out produced with Ucinet (Bartolli 2002) is presented in
Figure 7 using the data aggregated over the whole 1980-2003 period. Given the limited ability to interpret the results, no attempt was made to break down our analysis over the whole time period.

Figure 7: Non-metric MDS representation for the network of alliances and acquisitions during the 1980-2003 period using Ucinet (Bartolli 2002).
While caution should be used in interpreting the visual information\textsuperscript{13}, the MDS technique provides a simple way of visualizing the relative layout of the members within an industry. It also helps identify areas of clustering where groups of industry segments tend to collaborate more closely. The main observation is that the incumbent node (inc) is most central, followed by the imaging software (isw), hospitals (hos), medical devices (med) and service industry (ser) sub-groups. Industry segments on the periphery include research institutes (ri), government agencies (gov), venture capital firms (vc) and pharmaceutical distributors (phd).

4.2.3.2. Network graphs

Another useful tool for the visualization of the industry structure is the network graph with links connecting various industry sub-groups. Graphs for the period 1990-1999 and 2000-2003 are presented in Figure 8 and Figure 9. These graphs have been re-arranged manually to avoid overlaps and to provide better visual information. Their benefit is essentially to provide a visual representation and to rapidly identify sets of partners.

A high level comparison of both figures points to a couple of interesting observations. The overall layout evolves into a star-shape with fewer interconnections between peripheral players. At the center of the star we recognize the incumbent’s node (inc) and next to it the medical equipment node (mie).

\textsuperscript{13} In a case involving a large number of network members, Soh (2003) has reported a lack of correlation between the distance and the proximity of the firms in the spatial display.
Figure 8: Network graph of relationships or sub-industries during the period 1990-1999
4.2.3.3. Centrality measures

Building on the network of industry sub-groups presented earlier, we propose to look at a centrality measure as an alternative way to characterize the overall network structure. As stated in the literature review, the centrality flow betweenness measure is the most meaningful in identifying central players (Freeman 1979, Madhavan 1998). We present in Figure 10 the centrality measure using the Ucinet software (Bartolli 2002) for the industry sub-groups for the period of 1990-1999 and the period 2000-2003.

As we can see from the differences in centrality intensity, the later period is associated with an increase in centrality for incumbents (inc) and medical imaging firms (mie) at the expense of firms
in diagnostic substances (dgs) and pharmaceuticals (pha). This result matches our overall assessment derived from the visual inspection of the graphs and the overall trend towards consolidation reported in the industry overview. On a much lower scale, the analysis also shows a relative increase in centrality for the bio-technology firms (bio), the software firms (sft) and the service firms (ser).

To further characterize the overall structure of the industry, we can track the centralization index which measures the level of centralization for a particular layout. The centralization index is measured as:

Centralization index = (Σ Cmax – C(firm i)) / (n-1)

Where Cmax is the centrality of the most central node and n is the number of nodes in our network.

A centrality index of 100% corresponds to the extreme case of the “star shape” where all nodes are connected to a single node.

For our network of industry sub-groups, the centralization rises from 27% in the period of 1990-1999 to 47% in the period 2000-2003 and further confirms the trend observed so far. The detailed results from Ucinet are included in Appendix D – Centrality results.
Figure 10: Centrality flow betweenness for the sub-industries for the periods 1980-1989 and 1990-1999.
5. Analysis

The previous section has provided ample evidence of structural changes in the medical imaging industry. In this section, we analyze those structural trends. We are addressing the following questions:

- How can we interpret general trends in the evolution of the medical imaging industry network?
- How do these trends relate to the tendencies highlighted in our overview of the industry?
- Are there trends that are not visible in our structural analysis?

Our goal is to validate the extent to which this network view provides appropriate insights. It is also critical that we acknowledge the inherent limitations of such a framework.

To address those questions, we explore four main directions. First, we try to further clarify the role of central industry sub-groups: although we understand the structural implications, we have yet to give an interpretation of that centrality in the case of the medical imaging industry. Second, we discuss the trend toward increased centralization and suggest some underlying forces. Thirdly, we discuss the trend toward diversification and the emergence of new players: is this trend indicative of a larger shift in the industry? Finally, we explore the direction of expansion (i.e. horizontal vs. vertical) of the structural growth.

5.1.1. Centrality in the medical imaging network

What kind of benefits an industry sub-group can extract from its central position? To address this question, we have circulated a questionnaire to industry experts (Appendix C – Questionnaire on industry sub-group centrality). The questionnaire lays out four hypotheses for potential benefits of a network centrality. We asked experts to evaluate the six industry sub-groups considered to be the most central for the 2000-2003 period (Figure 10) against the four hypotheses. In decreasing order of centrality, the six industry sub-groups are: incumbents (inc), medical equipment (mie), diagnostic substance companies (dgs), biotech firms (bio), medical services (ser) and software (sft).
Hypothesis 1: Higher profits – The first hypothesis is that high centrality confers to a particular industry sub-group a strategic position of control in the value chain; this allows the industry sub-group to extract higher profits than the other players in that industry.

The consensus among our experts is that incumbents (inc group) have generally been very profitable. Leveraging on their central position in the network and the economy of scale intrinsic to their size and maturity they were able to extract profits above the industry average. To a limited extent, economies of scale have also helped large players in the diagnostic substance (dgs) and pharmaceutical industries (pha). Small medical equipment manufacturers (mie) on the other hand, occupy a central position in the network but face intense competition that has significantly limited profit margins. According to our experts two other industry sub-groups have been quite profitable: the IT related industry sub-group (sft) has benefited from the wider adoption of PACS systems and small focused players in that industry have been quite profitable; in the medical imaging service segment (ser) profits have also been above average as these companies through their flexibility have been able to leverage specific needs in the industry (tele-radiology, medical imaging services).

Hypothesis 2: Early adoption of innovation – The second hypothesis, is that central players have an advantage in anticipating technology changes and a tendency to adopt innovations ahead of other players in the industry because of their early access to information through their equity investments and alliances.

Incumbents are very well positioned for the early adoption of technology, as they have often built their centrality from equity investments in small start-ups. When a technology seems promising, they are in a good position to acquire it – either by acquiring a firm or by building the capacity internally using the knowledge gained over the life of their equity investment. This strategy, discussed by Roberts (1985), requires important resources that only large firms have. The ability of central firms to meet that criterion is largely conditioned by their resource capabilities. In reality however, other forces counterbalance these advantages and limit the effectiveness of large companies in absorbing innovations. First, due to their central position, these firms tend to be
overloaded by the flow of information (sometimes conflicting) they receive; managing that knowledge effectively represents a real challenge. Second, the well established firms usually have strong business reasons to hold off or to delay the inclusion of these innovations – because of the fear of cannibalizing their own products or because of internal resistance (i.e. Not-Invented-Here syndrome). To summarize centrality offers clear advantages for firms trying to channel innovations from smaller firms but, according to our experts, their ability to do it effectively is ultimately a function of their competence and execution skills as shown by the mixed records of incumbent firms.

**Hypothesis 3: Generation of innovation** – Similarly, we can argue that a central actor is able to leverage on its exclusive access to information and resources to launch new innovations before other players do (Madhavan 1998).

Consistent with the literature on the subject, our experts agree that the generation of innovations is largely orthogonal to the centrality measure and has two main sources. The first source of innovations results from investments in research combined with large internal capabilities: the category of firms that rely on that capability to innovate – in which incumbents fall – are however well known to be much more effective at incremental innovations that fall along the lines of their core competencies. The other path to innovations involves small start-up firms in the medical imaging industry that have produced significant innovations in a range of sub-industries related to medical imaging. These firms are usually well known for their ability to come up with more innovative ideas than the established firms (Christensen 1997). As far as industry sub-groups are concerned all five groups have been reasonably active, in large part by leveraging knowledge from the core technical areas and applying it to the medical imaging industry. To summarize, while centrality is viewed as an important asset that can stimulate the innovation process, its actual impact on the innovation process is minimal.

**Hypothesis 4: Promotion of new standards** – Finally, the role of central players in defining and promoting new standards is widely developed in the literature (Gower 2002, Gomes 1996).
In general, standards play a more important role in an industry when underlying technologies reach maturity and dominant designs are established (Utterback 1984). According to the experts we interviewed, all imaging modalities (including those most recently introduced) have reached that maturity level. The technologies are mostly well understood and the last 5 years have seen incremental improvements on top of those technologies. It is therefore quite surprising that, with the exception of the DICOM standard\textsuperscript{14}, standards have played a very limited role in that industry (see overview of Medical Imaging industry). Our experts indicate that incumbents have in fact little advantage to promote a standard that would undermine their hold on a particular market segment, unless it is requested by users – as was the case for the DICOM standard. This being said, experts agree that large established firms (e.g. incumbents) are clearly in a better position than smaller ones to push for a standard if they felt that they could benefit from it.

The results of the centrality empirical analysis are summarized in Table 4. The experts agree that in three out of the four cases (profit, taking innovation, and generating innovation) the centrality presents a competitive advantage for incumbent companies. However, those advantages seem to also greatly depend on other factors such as economies of scale, resources and strategic intent.

\textsuperscript{14} Some of the experts even dispute whether DICOM is a real standard given its many flavors.
<table>
<thead>
<tr>
<th>Centrality Criteria</th>
<th>Industry sub-group</th>
<th>High Profits</th>
<th>Early adopter of innovations</th>
<th>Generator of innovations</th>
<th>Promoter of new standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>+ + Economy of scale</td>
<td>+ Access to resources</td>
<td>+ Incremental innovations</td>
<td>+ If they wanted to</td>
</tr>
<tr>
<td></td>
<td>Incumbents (inc)</td>
<td></td>
<td>− NIH</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medical Equipment (mie)</td>
<td>− Competition</td>
<td>− No capital</td>
<td>+ Start-ups only</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diagnostic Substance Firm (dgs)</td>
<td>+ Economy of scale</td>
<td></td>
<td>+ Start-ups only</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biotech firms (bio)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medical Services (ser)</td>
<td>+ Flexibility, focused needs</td>
<td></td>
<td>+ Start-ups only</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Software (sft)</td>
<td>+ PACS related firm</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 4: Summary centrality evaluation based on the questionnaire in Appendix C.

5.1.2. Increased centralization

One of the main observations drawn from the network-level analysis is the increase in centralization as defined by the centralization measure. This trend is confirmed by visual inspections of Figure 8 and Figure 9. A couple of important factors may have contributed to this trend:

- First, the increased importance of complementary assets required for the development, testing and approval of new devices makes it difficult for small peripheral companies to embark alone in the commercialization of a medical imaging product. Given the existing trend toward consolidation, small companies will tend to be attracted to large well-established firms in central positions rather than taking the chance and ally with a peripheral company – even if the peripheral company has important financial resources but no central role. One alternate interpretation brings to mind the notion of social capital presented in our literature review: in the formation of industries, there is a strong tendency to reproduce and reinforce the existing network structure in order to maintain the value of the social capital. This was observed by Walker et al. (Walker et al, 1997) for the biotechnology industry. In the context of our analysis,
this means that a firm joining a particular industry sub-group will have a tendency to reproduce the relationships other members of its sub-group have with other sub-industries. What we observe is in fact different: while there is a tendency to reproduce the existing structure, there is also a trend towards a reduction of relationships with players in the periphery of the network. As a result, central actors become more central. In terms of social capital, this trend towards centralization can be seen as a trend toward reduction of social capital as the number of relationships between firms diminishes in favor of relationships with a single player. The main implication of such a result is that the resulting network is more vulnerable to opportunistic behavior (Walker 1997).

- Another factor that could account for the increase in centralization is the lack of major radical innovations in the medical imaging industry in the last 10 years. This hypothesis was proposed by Madhavan (Madhavan 1998) as he examined the dynamics of centrality in the steel industry. His claim is that, in the context of incremental innovations, firms in central positions are in a better position to generate innovations and to extract additional benefits from those innovations. In the process, they reinforce their central position. This assumption is consistent with other findings showing that large established firms have a natural tendency to concentrate on their existing technology and maintain their current performance trajectories (Christensen 1997). Our earlier discussion strongly supports this hypothesis.

5.1.3. Diversification and emergence of new players

The second important trend that emerges from the data presented above is a trend toward diversification of the players in the network and the emergence of new industry sub-groups. This trend is highlighted in Figure 6 where the industry categories in the periphery of the network are consistently more involved in alliances and acquisitions in the later time period (2000-2003). Within that group, the software (SFT) and the service industry (SRV) categories exhibit the most
noticeable increase. Within the software category, the increase was mainly fueled by alliances and acquisitions of firms developing general purpose software (sft). On the service side, the significant increase is mostly due to the increase in medical services (ser) resulting from the outsourcing of the imaging, the examination of radiology and billing. This trend is still in a very early phase but it could have a significant impact on the rest of the industry. As an example tele-radiology\textsuperscript{15}, enabled by the availability of standards such as DICOM, has given significant flexibility to hospitals – as they can now outsource the examination of medical images to make up for the shortage of radiologists and provide better service to their patients with 24 by 7 coverage. One of the implications is that the role of radiologists is likely to change as they are now further removed from the diagnostic environment and, as a consequence, the selection of the imaging systems is more likely to be left to hospitals or imaging centers. Another important trend in the medical service industry segment is the steady growth of diagnostic imaging centers that expect to capitalize on the 10% expected growth in MRI scan in the next 5 years\textsuperscript{16}.

5.1.4. Vertical versus Horizontal

The last part of this analysis focuses on the direction of the expansion of structural changes. In other words we examine whether the level of expansion of the inter-organizational network has been vertical (i.e. capturing more of the value chain) or rather horizontal (i.e. expanding the scope and breadth of the imaging modalities). To support our analysis, we present in Figure 11 a network graph aligned along the vertical and horizontal axis. In order to improve the readability, links were added only if two of more alliances or acquisitions took place between the two industry sub-groups. Nodes were positioned manually by following a couple of simple rules: generic suppliers are positioned below the industry segment they supply to; suppliers of complementary components are

\textsuperscript{15} Tele-radiology refers to the examination of medical images in remote locations

\textsuperscript{16} Bear Stearns, Health Care, Diagnostic Imaging Services, May 2003

66
positioned at the same level as their complementors. Some of the positioning may be arbitrary; the idea is only to capture the direction of activities across the network.

Figure 11: Network of medical imaging industry aligned along the vertical (supply) and horizontal axis (complementor). Acquisitions are indicated with curved arrows.

**Horizontal level** – At the horizontal level we can identify several threads of activities. Firstly one main thread is between incumbents (inc) and other medical imaging manufacturers (mie). This thread is consistent with our analysis in that it illustrates the highly complementary roles played by the two sub-groups: the smaller medical imaging firms bring innovations in new areas and rely heavily on complementary assets controlled by incumbents. A second thread is directed to providers of complementarity assets i.e. imaging software (isw) and diagnostic substances (dgs). These assets
are co-specialized (Teece 1986) in the sense that there is a complete tri-lateral dependence between the traditional medical imaging firms, the imaging software firms, and the manufacturers of diagnostic substances: medical imaging leverages on the appropriate combination of those three technologies and no single one can provide a complete solution. However a closer look reveals that these two assets (imaging software and diagnostic substance) are of a very different nature from the point of view of the incumbents. With respect to the technology *familiarity* dimension presented earlier in Table 2 imaging software falls within a set of familiar technologies that could easily be integrated through acquisitions, internal development or licensing (Quadrant VII); on the other hand the diagnostic substance segment falls in a different quadrant (Quadrant VIII) where the familiarity of incumbents is rather limited. With respect to the *clock speed* (Fine 1998) dimension, the two industry sub-groups are also dramatically different: imaging software has release cycles of 6 months to a year while diagnostic substance cycle has release cycles of up to several years. Differences along those two dimensions indicate that both industry segments should be approached by the incumbents differently. Finally, a thread links the incumbents (inc) and the medical imaging companies (mic) to suppliers of general software (sft) and suppliers of software for healthcare environment (hs).

**Vertical level** – On the vertical dimension, we observe that the level of activity can be broken down into three main groups. First, we find generic or specialized suppliers of either hardware (hardware components such as DSP boards, magnets, transducers) or software (software for archival); at the center, incumbents and various complementors; towards the end of the value chain, distributors, research institutions, service providers and hospitals. As pointed out earlier, these vertical relationships are, to a large extent, “controlled” by central players – i.e. incumbents, smaller medical imaging firms and providers of diagnostic substances who serve as hubs for the players at the periphery. However, the role of players at the end of the chain should not be downplayed: they have an important role in linking the central industry sub-groups with the final customers: the radiologists and to some extend the patients. As a reminder, we have underscored earlier the critical
role played by hospitals and research institutes in the innovation process as they experiment and push the boundaries of the technology available to them.

**Virtual integration** – As we consider the strength the medical imaging industry network, it is important to understand the extent to which the integration has been “virtual”, i.e. created through alliances rather than created through mergers and acquisitions. To answer that question we can refer again to Figure 11 in which acquisitions are represented by curved arrows. It appears clearly that acquisitions have taken place essentially along the horizontal axis with incumbents gaining in scope by acquiring smaller companies providing some of the complementary assets described earlier.

These trends at the horizontal level bring up what is possibly one of the most important developments in the industry i.e. the trend for incumbents to provide full solutions to their customers. While the major players in this industry have until recently focused on providing the best products, they also realize that customers are more interested in solutions with low cost of ownership. In practical terms, this means not only providing a complete portfolio of products but insuring that these products integrate seamlessly into the existing infrastructure of the healthcare provider, i.e. the health information system. In that sense, the industry is moving from focusing on the “best product” to focusing on “total solution” (Hax 2001). Another critical dimension of integration is along the workflow where vendors are trying to integrate the prevention, diagnosis, treatment and recovery phases: as several of the experts interviewed argued, the current system is a transaction based system with a very rudimentary handoff between those phases. Along the integration of the workflow, the role of imaging will be crucial as it will provide the continuum used to evaluate the progress and eradication of the disease. Efforts in the area of workflow redesign are promising; an interesting development is the involvement of process design firms such as IDEO17.

Finally, the integration of the treatment workflow can also be viewed from the technology angle.

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17 IDEO’s Design Cure – Can it fix the healthcare system? Metropolis Magazine, October 2002
While still many years away, experts in the industry view *molecular imaging* as a potential *technology platform* on which the integration of the workflow will take place. Molecular imaging has indeed the potential to address all phases of intervention from the prevention to the recovery. It is in this context that we need to understand the acquisition of diagnostic substance firms by incumbents\(^\text{18}\). However, many questioned how synergies can be found effectively between two very different industry sectors, when their core technological competencies and clock speeds are so far apart.

\(^{18}\) A well publicized example has been the acquisition of Amersham by GE for almost $10 billions.
6. A Dynamic Model for the Industry

We have reviewed some of the major trends affecting the structure of the medical imaging industry (Section 5) and we now focus on a synthesis of this information into a coherent system dynamics model. This model attempts to capture the various forces that re-enforce and/ or erode the central roles played by the incumbents. This analysis draws upon several of the trends highlighted in this research. After a detailed presentation of the key components of our model, we analyze a couple of scenarios.

6.1. Overall model

Our system dynamics model combines major trends identified in the previous section in order to capture the most important dynamics. The overall model is presented in Figure 12 and includes a series of re-enforcing and balancing loops. We will study each one of these loops before we examine how they interact with each other. At that point we will emphasize the importance of each one of the loops. The convention used in these diagrams is that the arrow represents a causal relationship from one variable to another. The sign at the arrowhead indicates whether the effect is positively (+) or negatively (-) related to the cause (Sterman 2000).
Figure 12: Overall system dynamics model of the medical imaging industry
6.1.1. The re-enforcing and balancing loops

Figure 13: Basic loops

"Musical Chair" (R1) and "Stuck" (B2) – These two basic loops capture the pressure and counter-pressure that push firms to enter in alliances within an industry. As an industry develops and as new players enter that industry, there is pressure for those players to partner as soon as possible with one of the incumbents in order for them not to be left out without a partner. This pressure is especially strong in an industry where the role of complementary assets is as important as it is in the medical imaging industry. In general, the incumbent will try to avoid redundant relationships with two equivalent firms (equivalent in the sense that they would both offer comparable access to new resources). The first firm that establishes a relationship automatically locks out other similar players.

This re-enforcing loop is referred to as the “musical chair” loop. The effect of this loop is mitigated by the “Stuck” loop: while there is pressure to ally early in the game to secure a good position with an incumbent, small firms also realize that a premature decision to ally carries the risk of being “stuck” with the wrong partner – as switching allies is not easy. As we have pointed out in our literature review, a firm joining a network of firms contributes indirectly to further strengthen the
“social capital” of the overall network – building its reputation as it abides by the norms of cooperation (Walker 1997). Reneging on some relationships may lead to wasted “social capital” – moreover, it may increase the difficulty for the firm to find new ally(ies) in the future.

**Figure 14: Loop showing the impact of increased vulnerability**

“**Forced to ally**” (R3) and “**Forced to merge**” (R4) – As incumbents control a large proportion of complementary assets, complementary assets available become scarce. This tends to increase the vulnerability of small and medium firms which will then be more likely to either enter into alliances with one of the incumbents or try to be acquired. In both cases, the centrality of the incumbent firms is further re-enforced. This trend has been one of the main drivers for the consolidation of the medical imaging industry as incumbents have been pressured to grow in an environment with stagnating revenues.
“Complexity” (R5) and “Best-of-breed” (B6) – We now examine the impact of the improvements in medical imaging technology with two main loops. As the centrality of the incumbent firms increases, competition between incumbents encourages investments in R&D. As noted earlier, these investments are usually above 10% of sales. These investments translate into technology improvements and increased complexity\(^\text{19}\). The high level of complexity (and the associated high price) emphasizes the role of complementary assets such as financing options, technical support and maintenance service. This in turn increases the propensity of small firms to ally with one of the

\(^{19}\) As a note, an MRI has typically over 40,000 parts and its price tag ranges from $1 to $3 millions
incumbents, further re-enforcing the centrality of major players. However the effect of this loop is mitigated by the balancing loop labeled “Best-of-breed” (B6): as incumbents further improve their technology and as a result, the imaging devices, each incumbent is likely to further differentiate and improve selected product lines where they have strong technical competencies. As they do that, the pressure for healthcare institutions to choose the best product in each category (best-of-breed) rather than sticking to a single vendor is likely to increase. This, in turn, encourages higher level of standardization and interoperability which reduces the relevance of complementary assets.
"Demand for improvements" (R7) and "Saturation of improvements" (B8) – These two loops share many of the dynamics of the "complexity" loop but they focus on the impact of the perceived improvements – resulting from the actual improvement in the underlying technology. The reasoning is that the behavior of a buyer of medical imaging equipment is significantly affected by his/her perception that the technology improvements may significantly impact his/her ability to
perform his/her work better. If, on one hand, a radiologist recognizes major benefits in the latest version of an MRI machine because its resolution allows him to better diagnose a particular disease, he/she will be willing to pay a high price for it (or a higher price than an earlier version of the same machine). On the other hand, if the radiologist believes that the progress in the technology is being done for technology sake and is not leading to significant improvement in his/her work, his/her willingness to pay more for the latest MRI machine is unlikely – e.g. if the resolution exceeds what is needed by the radiologist and the benefits along that specific dimension have saturated, there may be progress in technology but there is no perceived improvement. A good analogy can be found in the microprocessor industry where Intel has decided recently to downplay the importance of the clock speed as the benefits of that feature were being questioned by the public. Price sensitivity of the buyers of medical imaging equipment is very much affected by their overall perception of improvements; as perceived benefits decrease, the price sensitivity increases and may erode the role of complementary assets.

Figure 17: The development of new clinical applications
“New applications” (R10) – This re-enforcing loop centers on the attractiveness of the industry. With technical improvements, the range of clinical applications has significantly increased: this trend has been particularly strong in the last couple of years and an ever increasing number of medical conditions can now be diagnosed using one or more of the imaging modalities. The impact of this loop over the whole equilibrium of the system is that an attractive industry fuels the emergence of new technical sub-fields with start-ups interested in cashing in on some of those applications. As a result, the technology further improves.

Figure 18: Decentralization forces
“Decentralization towards services” (B11) and “Decentralization towards co-specialized assets” (B12) – These two balancing loops capture two forces that will tend to work against the existing centralization of the industry by creating new centers of value creation. The first balancing loop (B11) emphasizes the role of service companies in limiting the importance of the traditional complementary assets. As the industry becomes more attractive and the number of service organizations increases, the emphasis of those service organizations on low cost and their increased bargaining power reduces the traditional role of complementary assets controlled by incumbents. As a result, incumbents become less attractive as alliance partners and their central role begins to erode. As a consequence, the focus of incumbent firms shifts away from direct competition with other incumbents towards addressing the needs of service organizations. This trend tends to reduce the overall investments in R&D and to slow down the rate of technological innovations.

The second balancing loop is driven by the increasing role of co-specialized assets i.e. contrast agents. With the development of molecular imaging, contrast agents play an ever increasing role in the imaging process. Companies controlling those assets may be in an ideal position to extract additional value from these substances. This trend may create a new hub in the industry – i.e. weakening the attractiveness of incumbents and thus reducing their centrality.

6.1.2. Exogenous variables

Several exogenous variables have been included in the model.

Pressure to grow – This variable highlights one of the key drivers for large established firms to further innovate and to create some growth through the acquisition of new profitable businesses. This variable reflects shareholders’ expectation and depends largely on how well the firm has been able to deliver value up to that point.

Favorable re-imbursement policies – Re-imbursement policies have a great impact on the attractiveness of the industry. Medical imaging is often used when a patient visits a healthcare institution; if additional procedures are reimbursed by insurance companies; medical imaging use
would grow significantly. The key here is how well the medical research community will be able to
demonstrate clearly the long-term benefit of certain diagnostic procedures in reducing the overall
cost of healthcare. This issue will be further discussed in the next section.

**Positive macro-factors** – Some macro-factors also tend to gradually increase the attractiveness of
this industry. One of these factors is the aging of the population: for elderly patients the
attractiveness of non-invasive diagnostic technique is significant. Other factors include the steady
increase in certain types of disease diagnosed through one of imaging modalities (cancer,
cardio-vascular diseases).

### 6.2. Some Implications

The model presented in Figure 12 raises a couple of important implications:

**Continued centralization** – The central force captured by the model is a force toward increased
consolidation. The main driver for that consolidation is the critical role played by complementary
assets which limits the availability of alternatives to small firms and further re-enforces the position
of key players in the medical imaging industry. In that context, the model highlights that both the
increased complexity and the high price tag attached to medical imaging devices contribute to
accentuate the role of complementary assets. In addition, the continued disparity in local regulation
for medical equipment plays in favor of the established firms.

**Erosion of complementary assets** – A straightforward consequence of the argument presented in
the previous section is that an erosion of the role of complementary assets would greatly affect the
ability of incumbents to retain their central position. Several trends could contribute to that erosion:
first, further technical developments might result in the emergence of much differentiated imaging
products which would encourage purchasing organizations to request support for best-of-breed. As
a result, standards will have to be further developed to allow the coexistence of many brands within
the same health care environment and this trend will greatly weaken the position of the established
firms. A second trend that may also erode the importance of complementary assets is increased price sensitivity. Experts argue that the low level of price sensitivity is the result from the continuous rate of improvements perceived by the radiologists and to some extent, the public. As technology reaches a level of saturation and ceases to bring additional perceived improvements to the quality of the diagnostic, price sensitivity would increase. This trend would favor price competitive brands and may seriously jeopardize established complementary assets.

**Influencing reimbursement policies** – As mentioned earlier, the attractiveness of the industry hinges to a large extent on how much long-term benefit can be shown for specific diagnostic procedures. The major players and the various medical institutions play a large role in determining some of those benefits. In that respect, ongoing research on bio-markers could provide a great boost in that direction: some bio-markers detectable through imaging are uncritically correlated with the onset of particular diseases, and the ability to address preventively these diseases could be linked to a simple imaging diagnostic test. While the cost of screening randomly may be prohibitive, in some cases, the cost benefit of an early screening test outweighs the cost of treatment. Another avenue for influencing the reimbursement policies is to link more closely the diagnosis and treatment of certain conditions. In other words, the treatment could take place during or just after the diagnosis phase: this avoids the need for an additional visit to the healthcare center and if the procedure is invasive, it would eliminate the need for the patient to go through that procedure twice. Demonstrating the value of those trade-offs will be one of the challenges of the medical imaging community.

**Increased role of medical services** – The model suggests that medical services can play a significant role in redefining the centrality of incumbents. The core idea is that the medical imaging service firms would in essence redefine the role of diagnostic imaging and in doing so, change the role of complementary assets. Our research has indicated that this industry segment, while still
marginalized, has become a key player in that industry — acting as a broker between various parts of the delivery chain. In fact, in the case of the medical imaging services, these companies have direct contact with the patient, a position they may benefit from. In all cases, the economics driving those companies will differ significantly from the drivers that have affected the more traditional places where diagnostic imaging is being done: with a clear focus on cost and economies of scale, their price sensitivity will question the role of the traditional complementary assets. Finally, as we review some of the other dynamics discussed so far, we can anticipate that the role of this industry segment will be further re-enforced if for example the reimbursement policies become significantly more favorable for medical imaging: the ability of existing healthcare institutions to absorb that additional demand may be limited and medical imaging service organizations, with a focus on economy of scales, would be in a great position to absorb that additional demand.

**Increased role of contrast agents** — As some of the core re-enforcing forces weaken (e.g. saturation of imaging technologies), the role of contrast agents may increase significantly. We have discussed repeatedly how the development of these chemical and biological agents has the potential of redefining the role of imaging. The unknowns at this point are whether this potential can be fully realized (see exogenous variable “Ability to tag molecules”) and whether the producer of those contrast agents can be granted enough protection for their IP (see exogenous variable “Ability to protect IP”). Assuming it is the case, it is quite conceivable that these agents would work indiscriminately across many medical imaging devices and as those devices become more and more of a commodity, there is an opportunity for a shift in value creation from imaging devices to contrast agents. How can incumbents respond to that threat? For reasons mentioned earlier, we believe that the integration of these skills by incumbents will represent major challenges. Another option would be a further refinement of medical imaging devices to work more in tandem with particular contrast agents for which they would provide optimal performance. This would allow the medical imaging device to maintain some level of control on the overall imaging platform.
7. Conclusion

With the increase in strategic alliances and acquisitions, the firm needs to be studied in the context of the network of relationships in which it is embedded. This network not only extends the capabilities of the firm by establishing channels to access additional resources but it also creates additional constraints that have to be accounted for. This fundamental view was the backdrop of this research on the dynamics of the diagnostic medical imaging industry.

The first part of the research focused on developing the framework to analyze the structure of the industry. By combining a list of alliances and acquisitions with a list of approximately 30 industry sub-groups identified in the medical imaging industry we generated a network illustrating relationships between industry players. This network, that tries to capture the “true” underlying structure of the industry, was at the basis of our analysis.

In order to assess the evolution of that structure, a couple of network-based metrics (including network centrality) were measured over the periods 1980-1989, 1990-1999 and 2000-2003. The consolidation of the industry in the last 10 years is mirrored by an increase in the centralization index: the evolution of this index indicates that incumbents have increasingly occupied a more central position in the overall industry network. One important implication of the increased centralization, as suggested by Walker (Walker 1997), is that the overall “social capital” has diminished: with fewer relationships among themselves in favor of alliances with incumbents, norms of cooperation are less uniform and as a result, the whole industry is more vulnerable to opportunistic behavior, i.e. more instable. This view, while only based on empirical evidence, indicates that the medical imaging industry is riper than it may appear for major structural changes.

A parallel development identified in the analysis has been an increase in the role played by certain industry subgroups such as the medical imaging services and firms involved in the development of healthcare infrastructure software. This trend is also consistent with our understanding of the
industry.

We then tried to examine what kind of advantages the centrality confers to a particular industry subgroup: do firms in a central industry segment extract more profits? Can they adopt or generate innovations ahead of other sub-groups in the industry? Are they in a better position to promote standards? As expected, responses to those questions are mixed: while the experts we interviewed generally agreed that centrality does provide certain advantages, the ability to extract value from these advantages depends on other factors such as the resources available to the firm, the regulatory environment and the level of competition within that industry sub-group. Incumbents have been able to extract significant profits from their central position through economies of scale while smaller medical imaging firms facing significant competition and a lack of control on complementary assets have only been marginally profitable. On the innovations side, incumbents have generally leveraged quite effectively their resources and central location to make equity investments in small companies and get a better view of the new technical subfields. However, their ability to “absorb” innovations through joint-ventures or acquisitions has by all accounts exceeded their ability to generate innovations.

Overall the absorption of capabilities through alliances or acquisitions has allowed incumbents to increase the “scope” of the technology they offer. This has also allowed them to offer a richer selection of products – and to be perceived as total solution providers. One important follow-up question is whether we can envision a move toward a common diagnostic imaging platform: this platform would span the complete treatment cycle and have major implications on the current model in place in healthcare centers. While this is not likely to happen in the near future, the trend exists and has already started to affect the positioning of the incumbents.

The system dynamics presented in the final section offers some scenarios on how this industry might evolve. Our assessment is that while several forces are currently re-enforcing the centrality of our incumbents, the emergence of other centers of activity may defocus that industry. We suggest
that both the development of medical imaging service organizations and the increased role of contrast agents could serve as catalysts for this decentralization, by capturing some of the value currently controlled by the incumbents. A key question remains: how will incumbents respond to this threat? Recent developments give us some indications.

How insightful is our network centric framework? It has given us a fairly accurate “internal image” of the medical imaging industry. Our conclusions were shared by the industry experts and confirmed by the data generated. However, we do realize that we have introduced distortion in our measurements with the discrepancies in the reporting of alliances and acquisitions. In addition, we have considered relationships as simply binary with no attention to the specifics of the alliances in place. We believe that by taking into account the “strength” and specificities of the relationships, the overall view could be significantly improved.
Glossary

**Angiography** – Angiography is used to display blood vessels by means of contrast agents, which is subsequently filtered through the kidney.

**Biomarkers** – A biomarker is a laboratory measurement or physical sign used as a substitute for a clinically meaningful endpoint that measures directly how a patient feels, functions or survives.

**CAD** – Computer Aided Detection – Computer aided detection refers to a set of pattern recognition techniques used to help the radiologist in the diagnosis of certain conditions.

**CAT** – Computerized Axial Tomography – Old name for what is now CT

**CT** – Computer Tomography – See Appendix A.

**DICOM** – Digital Imaging and Communications in Medicine standard

**Fluoroscopy** - As compared to conventional radiography where individual images are generated, fluoroscopy displays the progression of movement under continuous radiation for the purpose of monitoring.

**HCFA** – Health Care Financing Administration

**HIS** – Hospital Information System.

**Molecular Imaging** – Molecular imaging can be defined as the measurement and/or imaging of biological processes in *living organism* at the molecular and cellular level

**PACS** – Picture Archiving and Communications System

**PET** – Positron emission tomography – See Appendix A.

**RIS** – Radiology Information System. RIS links the information system of a hospital with the image database systems (PACS).
Appendix A – Classes of Diagnostics Imaging Modalities

X-ray – Invented over 100 years ago, X-ray is the oldest imaging technique. It is an analog technology in the sense that image is stored on a physical film and examined by projecting the image using film-screen technology. It currently accounts for around 65% of all diagnostic examinations. With the push for complete digital solutions, a couple of digital substitutes have started to take hold. Computed radiography (CR) stores the images in a digital form and has the advantages of being fully compatible with the traditional X-ray equipment. Digital radiography (DR) on the other hand requires completely new equipment and the high cost has been an impediment to a wider adoption. These two new technologies have overall limited the growth of the traditional X-ray machines as hospitals wait for prices to fall before updating their equipment.

Computed Tomography (CT) – Computed tomography was introduced in 1973 and is a fully digital technique based on a rotating X-ray assembly. As the body is being irradiated from multiple angles, the detectors on the opposite sides collect cross-sectional images that are collected and re-assembled using a computer. The procedure is typically time-consuming, requiring 15-20 seconds with the latest technology. In recent years the use of contrast agents in combination with CT has increased and in 1994, 44% of the CTs were done with contrast agents.

Nuclear medicine – Developed in the late 50s and used in diagnostics since the late 60s, nuclear medicine refers to images that are produced by mapping the distribution of a radio-active substance (tracer) that was previously injected or ingested. Nuclear medicine is extensively used for functional imaging which tries to assess how well an organ is functioning by monitoring the inflow, accumulation or outflow into and from a particular organ. Positron emission tomography (PET) is a particular class of nuclear medicine technique based a special category of tracers, positron-emitting isotopes.

Magnetic Resonance (MR) – Magnetic resonance is the most recent technique based introduced in the early 80s. It requires a strong magnetic field (typically produced by a large magnet) and the
interferences of the magnetic field with certain substance such as hydrogen are captured by a computer which produces images. It is particular useful to visualize the brain, spine and certain joints. More recently, MR has been combined with contrast agents and used for other body areas and for examining the vascular system.

**Ultrasound** – Introduced in the early 70s ultrasound is a digital technique based generating images from the echo of high frequency sound waves. Ultrasound has the advantages of not requiring radiation or the ingestion of tracers which makes it particularly appealing for obstetrics use. In addition it can generate images in real time, for both static of dynamic purposes. The Doppler ultrasound can recognize the flow of blood and is used in diagnosing blood vessel problems. It is worth pointing out that the ultrasound market has typically been a different market than the traditional market for medical imaging: where as in the traditional market, the main user of those images is the radiologist, for ultrasound, the user can be many other specialists such as cardiologists, surgeons and obstetricians.
<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
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| X-Ray                         | • Invented over 100 years ago  
• Analog technology stored on physical film  
• Accounts for 65% of diagnostic examinations.  
• X-Ray angiography used for visualizing real-time blood flows (4.5 million a year.) |
| Computed Radiography          | • Digital technology  
• Fully compatible with X-Ray equipment |
| Digital Radiography           | • Digital substitute to X-Ray machine and computed radiography machines                                                                 |
| Computed Tomography (CT)      | • From 1975  
• 6,000 machines in the US and 26,000 worldwide  
• 21 million scans a year (USA, 1994)  
• 44% of the CT used in combination with contrast agent (1994)  
• New generation requires only 15-20 seconds for a complete study  
• Price: $0.5 – $1 million |
| Nuclear medicine (NM)         | • From 1960  
• Digital technology  
• Positron emission tomography (PET) is a special class of techniques relying on fluorine, oxygen and carbon  
• HCFA has agreed to pay for certain PET examinations  
• Extensively used for functional imaging.  
• Pet used for coronary artery disease, neurology, and oncology  
• 9.1 million a year (1994)  
• Price: $0.5-2 million |
| Magnetic Resonance Imaging (MRI)| • From 1980  
• Digital technology  
• No ionizing radiation  
• Requires homogeneous magnetic fields produced by magnets.  
• Good for brain, spine  
• 7.4 million a year (USA, 1994)  
• 29% used contrast agent. (1994)  
• Requires around half an hour for brain  
• Price: $1-3 millions |
| Ultrasound                    | • From 1970  
• Digital technology without ionizing radiation  
• Images generated from echoes of high frequency sound waves.  
• Can be static or dynamic. Doppler ultrasound for measuring blood flows.  
• Used by many specialists beside radiologists. Until recently, market dominated by outsiders.  
• Inexpensive / Large installed base / Real time / Safe / Ease of use  
• Ultrasound starting to get used in surgery.  
• Price: $50-300 k |

Table 5: Data and numbers for medical imaging modalities
Appendix B – Alliance types and their description

<table>
<thead>
<tr>
<th>Relationship type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition</td>
<td>In an Acquisition agreement, the Client Company acquires legal control (greater than 50% of voting shares) of the R&amp;D Company, including both assets and liabilities.</td>
</tr>
<tr>
<td>Asset Purchase</td>
<td>An Asset Purchase is an agreement in which the Client Company acquires legal control of one or more physical assets, such as manufacturing plants or business units, from the R&amp;D Company.</td>
</tr>
<tr>
<td>Assignment</td>
<td>In an Assignment agreement, the R&amp;D company transfers title or legal interest in an intellectual property asset to the Client company.</td>
</tr>
<tr>
<td>Co-Development</td>
<td>In a Co-Development agreement, both parties participate to some degree in the clinical development of a compound or project within a licensed territory and the Client company does not fully reimburse development expenses incurred by the R&amp;D company.</td>
</tr>
<tr>
<td>Co-Market</td>
<td>A Co-Market agreement defines a commercialization venture whereby two or more parties promote and sell a single product with each party obtaining sales revenues and/or net profits only from its own sales of the product.</td>
</tr>
<tr>
<td>Co-Promotion</td>
<td>A Co-Promotion agreement defines a commercialization venture in which two or more parties promote and sell a single product, with each party obtaining sales revenues and/or net profits from either party's sales of the product.</td>
</tr>
<tr>
<td>Collaboration</td>
<td>In a Collaboration agreement, two or more parties perform research and/or development activities in a single R&amp;D program.</td>
</tr>
<tr>
<td>Compatibility</td>
<td>In a compatibility agreement both parties agree to expose interfaces to allow compatibility between two or more devices.</td>
</tr>
<tr>
<td>Cross-License</td>
<td>In a Cross-License agreement, one party obtains a license to an intellectual property asset (e.g. a patent) in at least partial exchange for granting a license to its own intellectual property asset.</td>
</tr>
<tr>
<td>Development</td>
<td>In a Development agreement a sponsoring party engages another party to perform R&amp;D services beyond the stage of lead generation.</td>
</tr>
<tr>
<td>Distribution</td>
<td>In a Distribution agreement one party is engaged to promote or sell a product in final manufactured form as supplied by the originating party.</td>
</tr>
<tr>
<td>Equity Agreement</td>
<td>An Equity agreement describes the issuance of a minority share (&lt;50%) of legal ownership interest in an entity.</td>
</tr>
<tr>
<td>Joint Venture</td>
<td>A Joint Venture agreement concerns the legal creation of a separate entity (i.e. corporation, partnership, or limited liability corporation) by two or more parties.</td>
</tr>
<tr>
<td>Lead Deployment</td>
<td>An agreement to deploy some state-of-the-art systems for identifying needs and uses.</td>
</tr>
<tr>
<td>Letter of Intent</td>
<td>A Letter of Intent is a written description of economic terms and any other principle elements of an agreement between two parties. It may be binding or non-binding.</td>
</tr>
<tr>
<td>License</td>
<td>A License is a written agreement whereby one party obtains permission to make, have made, use, sell, or have sold an intellectual property asset (e.g. a patent or compound) from another party.</td>
</tr>
<tr>
<td>Category</td>
<td>Definition</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>Loan</td>
<td>A Loan is a payment or promise of future payment from one party to another whereby such payment is repayable (either with cash, equity, or a combination of the two) at a future time.</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>In a Manufacturing agreement, the Client company will make or have made a product for use or sale by the R&amp;D company.</td>
</tr>
<tr>
<td>Marketing</td>
<td>In a Marketing agreement, the Client company obtains certain rights to a product not otherwise disclosed or classified. A Marketing agreement is a commercialization designation that does not meet the criteria of either a License or a Distribution agreement.</td>
</tr>
<tr>
<td>Merger</td>
<td>In a Merger agreement legal control (50%+) of two entities passes to a third entity from which the business of the two will be conducted on an ongoing basis.</td>
</tr>
<tr>
<td>Option</td>
<td>An Option is a legal right, acquired for some consideration, for a party to gain access or license to an asset at some future time for fixed economic terms.</td>
</tr>
<tr>
<td>Research</td>
<td>In a Research agreement, a sponsoring party engages another party to perform R&amp;D services in the discovery and/or lead stages of an R&amp;D project.</td>
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<tr>
<td>Security</td>
<td>A Security is a legal interest in an asset given by one party to another as a pledge of repayment of a loan or other obligation.</td>
</tr>
<tr>
<td>Settlement</td>
<td>A Settlement is a written agreement following litigation or another dispute between two or more parties.</td>
</tr>
<tr>
<td>Sublicense</td>
<td>A Sublicense concerns the conveyance of a license from one party to another, wherein that license was earlier granted to the conveyor by a third party.</td>
</tr>
<tr>
<td>Supply</td>
<td>In a Supply agreement, the R&amp;D company will make or have made a product for use or sale by the Client company.</td>
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<tr>
<td>Termination</td>
<td>A Termination agreement concludes or dissolves an earlier arrangement between two companies.</td>
</tr>
<tr>
<td>Warrant</td>
<td>A Warrant is the issuance of a future share of legal ownership interest in an entity whereby the acquirer has the option, but not the obligation, to purchase such ownership interest for a designated period of time for fixed economic terms.</td>
</tr>
</tbody>
</table>

Table 6: Categories of relationship used to classify all alliances and acquisitions. Based on the types provided on the Recap database, with the addition of the “lead deployment” and “compatibility alliance”
Appendix C – Questionnaire on industry sub-group centrality

Philippe Jeanrenaud

MIT Sloan School

Management of Technology 2004

Questionnaire for the research on

“The Dynamics and Architecture of Value Networks – The Case of the Medical Imaging Industry “

Context

The study examines the structure of the medical imaging industry.

By compiling a list of alliances and acquisitions in the last 5 years, we inferred a inter-organizational network describing the industry. From that network, we identified a set of firms and sub-industries that are dominant in terms of their “centrality”. The goal of this questionnaire is to have experts in the medical imaging industry validate this centrality around several criteria.
For each sub-industry, you are asked to assess the extent to which firms in that sub-industry meets any of the centrality criteria listed. To do that, please rate for each sub-industry listed here against each criteria on a scale from 1 to 5 where

1 = strongly disagree and 5 = strongly agree.

<table>
<thead>
<tr>
<th>Centrality Criteria</th>
<th>Incumbents (inc)</th>
<th>Medical Equipment (mie)</th>
<th>Diagnostic Substance Firm (dgs)</th>
<th>Biotech firms (bio)</th>
<th>Pharmaceutics Firm (pha)</th>
<th>Imaging software (isw)</th>
<th>Other? **</th>
</tr>
</thead>
<tbody>
<tr>
<td>A central has higher profits than other firms in that industry</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A central firm is an early adopter of new innovations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A central firm is a generator of innovations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>A central firm is able to better promote or control new standards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any other characteristics that can be associated with firms in that sub-industry?</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

* For more information about the industry, please refer to the next page.

** Suggest if possible a sub-industry not included here that would in some sense meet one of the criteria listed
List of sub-industries used for the research (from Hoovers) – Central sub-industries are highlighted

<table>
<thead>
<tr>
<th>Description</th>
<th>Code</th>
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</thead>
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<tr>
<td><strong>Medical imaging incumbents</strong> - Includes GE, Siemens, Philips and Kodak</td>
<td>GE,SIE, PHIL,KOD</td>
</tr>
<tr>
<td>Medical devices - A firm developing medical imaging devices such as transducers.</td>
<td>med</td>
</tr>
<tr>
<td>Medical equipment - A firm developing medical imaging equipment such as ultrasound, CT scanner, MRI systems (R2 technologies, Baxter, Becton Dickinson, Elscint, ...).</td>
<td>mie</td>
</tr>
<tr>
<td>Pharmaceuticals - Traditional large pharmaceutical companies (Merck, Schering, Abbott, ...)</td>
<td>pha</td>
</tr>
<tr>
<td>Pharmaceuticals biopharma - Small pharmaceutical firms focused on large molecules than traditional pharmaceutical companies. (Applera, Centocor, ...)</td>
<td>bph</td>
</tr>
<tr>
<td>Pharmaceuticals diagnostic substance - Pharmaceutical companies selling diagnostic substances. (Nycomed, Epix, Genometrix, Mallinckrodt, ...)</td>
<td>dgs</td>
</tr>
<tr>
<td>Chemicals - A firm developing and selling chemicals</td>
<td>chm</td>
</tr>
<tr>
<td>Biotechnology firm - Traditional large biotechnology firm (Genentech, Millennium, Biogen, ...)</td>
<td>bio</td>
</tr>
<tr>
<td>Biotechnology research equipment - A firm involved in the development research equipment for biotechnology</td>
<td>bre</td>
</tr>
<tr>
<td>Biotechnology services - A firm providing biotechnology services</td>
<td>bts</td>
</tr>
<tr>
<td>Imaging software - A firm developing imaging software such as 3D and 4D visualization tools or computer aided diagnostic (CAD) tools. (ISG, AccuImage, RSI, ...)</td>
<td>isw</td>
</tr>
<tr>
<td>Software - Firm developing general purpose software such as networking</td>
<td>sft</td>
</tr>
<tr>
<td>Software archival - Firm developing software used for general archival and archival of images.</td>
<td>swa</td>
</tr>
<tr>
<td>Healthcare software - A firm developing and selling software for healthcare management.</td>
<td>hs</td>
</tr>
<tr>
<td>Computer hardware - A firm selling computer hardware</td>
<td>cmp</td>
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<tr>
<td>Imaging equipment - A firm manufacturing general purpose imaging equipment such as displays.</td>
<td>img</td>
</tr>
<tr>
<td>Mechanical components - A firm manufacturing and selling mechanical components such as magnets.</td>
<td>mec</td>
</tr>
<tr>
<td>Hardware components - A firm manufacturing and selling hardware components such as DSP cards, storage devices.</td>
<td>hard</td>
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<tr>
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<tr>
<td>Computer services - A firm offering services for computers</td>
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<tr>
<td>Medical services - Firm providing medical specific services such as purchasing, billing, tele-radiology</td>
<td>ser</td>
</tr>
<tr>
<td>Medical lab - Medical laboratories that perform exams</td>
<td>lab</td>
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<tr>
<td>Distributor - A general distributor of diagnostic imaging equipment</td>
<td>dist</td>
</tr>
<tr>
<td>Pharmaceuticals distribution - Firm involved in the distribution of pharmaceutical substance.</td>
<td>phd</td>
</tr>
<tr>
<td>Hospital - Hospitals with research facilities</td>
<td>hos</td>
</tr>
<tr>
<td>University - University of research centers tied to university.</td>
<td>uni</td>
</tr>
<tr>
<td>Research institute - Institutes focused on basic research</td>
<td>ri</td>
</tr>
<tr>
<td>Venture capital - Venture capital firm.</td>
<td>vc</td>
</tr>
<tr>
<td>Government agency - A government agency</td>
<td>gov</td>
</tr>
</tbody>
</table>
Appendix D – Centrality results

**Period 1990-1999**

FLOW BETWEENNESS CENTRALITY MEASURES

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Dataset is symmetric.

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27 uni  9.636  1.275
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Network Centralization Index = 27.619%

DESCRIPTIVE STATISTICS FOR EACH MEASURE

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Important note:
This version incorporates a new approach to implementing the Freeman et al concept of flow betweenness that can yield values that are different from those computed by versions of UCINET prior to 5.2.0.0

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Output generated: 22 Apr 04 12:46:56
Copyright (c) 1999-2000 Analytic Technologies
**Period 2000-2003**

FLOW BETWEENNESS CENTRALITY MEASURES

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Network Centralization Index = 46.997%

**DESCRIPTIVE STATISTICS FOR EACH MEASURE**

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Important note:

This version incorporates a new approach to implementing the Freeman et al. concept of flow betweenness that can yield values that are different from those computed by versions of UCINET prior to 5.2.0.0.
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