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THE ROLE OF MODULARITY IN KNOWLEDGE PROTECTION AND DIFFUSION: THE CASE OF NOKIA AND ERICSSON

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The Role of Modularity in Knowledge Protection and Diffusion: The Case of Nokia and Ericsson

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ABSTRACT

When network externalities are important for a product, there is often a move to introduce standards on the basis of product modularity such that product interfaces remain constant over time and across brands. This allows other firms to develop complementary products and services. However, introducing standardization can lead to a weakening of the technology developer's competitive position. Standardization makes much of the underlying product knowledge accessible, reducing barriers to entry such that other manufacturers are able to quickly develop comparable products. Thus in cases where network externalities are important and standardization needs to occur, there are also needs to protect knowledge that may form the basis for the developer's competitive position within the industry. To review the differing approaches to managing technical knowledge we deconstruct product architectures into clusters of technical knowledge that we refer to as information structures. We use the notion of knowledge structures to study how different components of a product architecture can be made open in the form of standards, whereas other elements can be heavily protected. To study these issues, we chose the mobile phone industry. Nokia and Ericsson were instrumental in developing the GSM standard and pushing for its institutionalising across Europe. However, both of these firms still remain dominant in the manufacture of mobile phones. Thus we sought to observe how they managed various clusters of technical knowledge such that the standard was open, a range of firms has produced complementary products, and yet Nokia and Ericsson's competitive position within the industry has not been diminished.

INTRODUCTION

Standards are important within the mobile (cellular) phone industry as they provide the basis for different phones from different manufacturers to be able to communicate with each other. More recently standards have also become important for the development of complementary products and services. Today's mobile phones interlink with a number of other 'smart technologies', are web enabled and in some countries, form the basis of a smart card system whereby they can be used to purchase basic products. When standards exist such that interface specifications are defined as a way of allowing other firms to develop complementary products and services, there is very often a loss of control over the technology. We draw upon the same examples used by industrial economists in discussing the role of standards to show that most firms that have developed a standard have later become just one of many producers of a particular product. That is, by adopting an open architecture, the developers of the technology ultimately lessened their competitive position. Examples include the RCA colour television standard and the Matsushita VHS videocassette recorder. Thus we suggest that in cases of network externalities, it is necessary for firms to purposely diffuse knowledge that relates to the standard to allow complementary firms to enter the system, and yet simultaneously protect the knowledge that underlies any competitive advantage that the firm may enjoy within the industry.

To consider how these dual, and potentially conflicting aims may be met, we deconstruct the product architectures into clusters of related technical knowledge that we call information structures and then further deconstruct these into component level knowledge. We propose that by using clusters of technical knowledge (or information structures), that it is possible to follow how complete sets of knowledge that underlie specific functions of the mobile phone are dealt with by mobile phone manufacturers.

Nokia and L. M. Ericsson are two of the big three mobile phone manufacturers in the world. Interestingly, both were instrumental in having the air interface protocol of GSM adopted initially as a pan-European standard, and later as the most popular standard in the world. They have managed to develop the GSM standard and to simultaneously draw numerous firms into developing complementary products and services. However, they have done all of this without their competitive positions within the industry being compromised. Applying the notion of information structures, we propose that there are three major clusters of technical information to do with mobile phones, and on the basis of our interviews with numerous managers at Nokia and Ericsson we show how the various information structures have been managed in different ways such that these firms' competitiveness has been enhanced rather than compromised.

THE ROLE OF STANDARDIZATION AND NETWORK EXTERNALITIES

The standardization of products can create significant benefits to both consumers and firms within an industry (Farrell and Saloner, 1985). Standardization allows for compatibility in terms of complementary products and services. For example, standardization of television broadcasts allow for different broadcasters to be received on different televisions. Similarly, different brands of stereo systems all play standard audio CDs. What standardization does is to keep all the interfaces of product constant such that a range of different firms can develop complementary products or services (Langlois and Robertson, 1992). That is, stereos from different manufacturers can operate in different ways internally but they must each be capable of reading standard CDs, accepting signals from other inputs such as a videocassette recorder for home theatre and outputting data in standard forms that can then drive any speaker system. Thus for standardization to occur, there must be consistency across the product architecture both over time and across brands in terms of interface specifications. For example, in the personal computer (PC) industry, ". . . for each layer of the network there are published standards and interface protocols that allow hardware and software products from many vendors to blend seamlessly into the network" (Morris and Ferguson, 1993: 88).

Standardization of products is particularly important when the benefit derived from the product is dependent upon the number and range of complementary products and services (that is, when network externalities are important). For example, the benefit that an owner of a videocassette recorder derives will be partially dependent upon the range of videos that are available for hire, the number of places that these videos can be hired from and the frequency of repair shops that can service the video recorder should a problem arise. The availability of these complementary products and services are often highly correlated with the number of people that use a compatible standard (in this case compatible video recorders). Hence it is important for manufacturers of a product whose success is dependent upon complementary products and services, that they standardize all product interfaces to easily allow other firms to develop the products and services that will support their product. This in turn will attract further users of the standard (the installed base), which then in a cyclical manner will most likely further increase the number of firms producing complementary products and services. The benefits of a large installed base reinforcing the dominance of a particular standard underlies Teece's (1986) notion of the benefits of a dominant design as one of the three building blocks for profiting from an innovation.

However, the pursuit of a large installed base, or the achievement of a dominant design has a number of downsides, the most common and significant being the loss of control over the technology. The classic example is the battle between the VHS and Betamax standards in the field of video recorders. In many respects the Betamax model by Sony was superior, however, the policy of licensing the VHS technology by Matsushita and flooding the market with VHS models allowed the VHS standard to win the battle as the number of complementary products and services far outnumbered the Betamax offerings (Cusumano, Myolandis and Rosenbloom, 1992). Today Matsushita is just one of many producers of VHS video recorders. Similar examples exist in other industries such as the computer industry where Sun started in the workstation market well behind Apollo. However, by creating an open architecture and allowing other suppliers to become involved, Sun rapidly overtook Apollo (Garud and Kumaraswamy, 1993). The problem for Sun now, is that they are fighting off new competitors in the workstation market that have entering the market using the same (open) architecture that Sun developed (Baldwin and Clark, 1997). Thus, success in industries where network externalities are important often comes from having a large installed base and attracting producers of complementary products and services. To attract these complementary firms, at least the interfaces need to be standardized, but in most cases, the whole product is standardized to the extent that it utilizes an open product architecture. This process can lower the barriers to entry to the industry and lessen the competitive position of the original innovator.

The benefits of standards when network externalities are important and the way that standards wars are played out through the use of the installed base, first mover advantages, complementary assets and other factors has been well covered through a collection of literature that is grounded in industrial economics (for example, see David and Greenstein, 1990; Farrell and Saloner, 1985; 1986; 1992; Katz and Shapiro, 1986; 1992 Shapiro and Varian, 1999). However, what is less well covered is the loss of control over the technology that can accompany the standardization process when appropriability regimes are not high (in that the technology cannot be easily protected). Reviewing many of the cases that these and other authors refer to (e.g. Hill, 1997; Chesbrough and Teece, 1996) in their work on standardization shows that in many cases the original innovator or developer of the technology eventually just became one of a number of manufacturers of the product. For example, consider how each of the following innovators of a standard are today just one of many producers of products within that standard: the Matsushita VHS video recorder, the IBM PC, the Sun workstation, the RCA colour television and Kodak 35mm film.

Thus, for products where network externalities are important, there are dual needs in terms of managing the technology. On one hand it is preferable to standardize interfaces such that complementary products and services are developed and so that the largest group of consumers possible adopts the technology. However, to avoid loss of control, the firm that developed the product should try and protect the knowledge that provides the product with a competitive advantage such that it cannot be easily incorporated into other firm's offerings.

To demonstrate these dual needs of sharing knowledge with complementary firms and simultaneously protecting knowledge, it is interesting to follow the story of Apple and the development of the Graphical User Interface (GUI) versus the PC. The first successful application of GUIs by Xerox was commercially unsuccessful, as it was an entirely closed system and so the product was not adequately supported in terms of software (that is network externalities were important, but complementary firms could not enter the larger production system). Apple, however, succeeded on their second attempt with the Macintosh (following the Lisa) as it allowed for third parties to become involved at the software development level through having an architecture that was not quite as closed (Morris and Ferguson, 1993). The most open system though, was the IBM PC. Through an open architecture, the PC by IBM (and clones) advanced very rapidly. Even though many believed the Macintosh to be a superior system, particularly prior to the introduction of Windows, the PC became the dominant design because of complementary products such as software and the rapid development of the product through having multiple suppliers involved. Thus an open architecture approach won the dominant design battle and created the largest installed base. However, IBM, the developer of the architecture, failed to benefit extensively from their innovation as it was easily replicated.

In much the same way, manufacturers of mobile phones face the same conundrum: opening up their architecture would allow for even more complementary products and services, thus ensuring success for the phone. However, it is also likely to lead to a loss of control, or at least it would allow competitors to more easily enter the industry and erode the position of the present market leaders. At this point, we move our discussion to deconstructing product architectures to explain how it is possible for a product architecture to contain elements that are open, and yet for other technical information to be protected.

KNOWLEDGE TYPES AND INFORMATION STRUCTURES

Complex systems are hierarchical in nature. It is possible to deconstruct systems into components, which in turn can be deconstructed into finer components and so on. Simon (1962: 26) provides a biological example whereby a biological organism can be deconstructed into "organs, which are composed of cells, which contain organelles, which are composed of molecules". In much the same way, complex products can be deconstructed. For example, a bicycle is made up of parts such as wheels, and wheels contain components such as hubs, and hubs contain ball bearings.

Deconstructing products can be interesting in that it allows us to see the various component parts involved. From an academic perspective, it forms the basis for much of the work done in the area of modularity (e.g. see Sanchez and Mahoney, 1996; Schilling, 2000; Ulrich, 1995). However, except in the development of modular product architectures or reverse engineering, few firms are overly concerned with the deconstruction process. Instead they are interested in the construction process, whereby components are combined in such a way as to create an operational system. Construction of a product using existing components and an existing product architecture (that is something akin to a set of instructions as to how components fit together) is relatively uncomplicated. Simply assemble the components as per the instructions. However, if you want to change any component within the system, particularly if you wish to innovate, then the task becomes far more complex. To start making changes at the component level, knowledge must exist as to the operation of the component in terms of how it works and why it works in a particular way (Galvin, 1999). Thus to construct a bicycle, a firm can simply assemble the components as per the defined architecture. To innovate though, requires an understanding of how each component works. For example, to change the ball bearings in the hub of a bicycle wheel would require an understanding of how the ball bearings work. That is, if you wanted to make the wheel spin more efficiently would you need ball bearings that are larger or smaller in diameter, or would it be preferable to use another input such as needle bearings? Thus to innovate and construct a product that does not already have a well-defined product architecture requires an understanding of how each component functions. The knowledge that creates this understanding is referred to in this paper as component level knowledge. Such a notion is not new. For example, Henderson and Clark (1990) differentiate between component level knowledge (how a component operates) and architectural knowledge (how components fit together to form a functional system).

Component level knowledge is the basic building block for being able to innovate in regard to complex products. However, to be able to alter complex products through changing components, there needs to be a higher level of understanding. In particular, there needs to be an understanding of how and why components must link with each other in a particular way. That is, there is a level of knowledge that builds upon component level knowledge to do with component interfaces and thus the operation of a component within a larger system. For example, to understand how each element of a bicycle wheel works and how a frame is constructed does not inform one that a design placing the wheels closer together will create a 'faster' more manoeuvrable bicycle, whereas a longer wheelbase will produce a more comfortable bicycle. It is this understanding of the interface, that when combined with component level knowledge that produces what we refer to in this paper as the information structure. The information structure is thus a knowledge map of how and why each component must link in with the other components of the product in a particular way for an operational product to result.

The concept of an information structure has received some coverage in the literature. Sanchez and Mahoney (1996) use the notion of an information structure to describe 'the glue' that allows a functional product to emerge from a series of interlinked components. In discussing modular products, they posit that a well defined information structure can act as an embedded form of coordination mechanism for loosely coupled organizational structures (as per Orton and Weick's (1990) conceptualisation of loosely coupled systems). In providing a definition of information structures, Galvin (1999: 469) describes an information structure as covering what components will be included in the system and their functions, knowledge of the physical and spatial connections between components and knowledge of how to measure performance and conformity of the components within the system. For the purposes of this paper, we use the same basic approach whereby the information structure includes the component level knowledge as well as defining how the components fit together spatially, functionally and physically on the basis of how they operate independently and interdependently. Thus in the case of the mobile phone industry, component level knowledge such as how and why the transmitters in mobile phones operate is the first step in being able to build an information structure that outlines how the transmitter and the various other components will be integrated into a complete system for signal processing such that voice and data can be effectively transferred between two users of mobile phones.

The information structure is thus a conglomerate of technical knowledge that includes both component level knowledge as well as knowledge of how all of these components fit together and interact to form a functional system (what is referred to as architectural knowledge by Henderson and Clark, 1990). In the case of complex products, we suggest that it is possible to have multiple information structures, as information structures are clusters of technical knowledge based around a group of interdependent components. For example, in a Walkman there may be one information structure concerning the driving of the tape and another to do with the reading and the production of music. There are a series of components from the power supply to the motor that turns the tape that would form one information structure as a cluster of knowledge based around a singular function. There is another that starts with the head mechanism and finishes with an amplified musical output through the headphones. This is a relatively independent cluster of knowledge in that it is possible to change the entire driving mechanism and as long as the new system still drives the tape spools then an operational product would still result.

This concept of independent clusters of knowledge is where the notion of information structures fundamentally differs from Henderson and Clark's writings about architectural knowledge. They posit that there is a level of knowledge that is based upon the component (component knowledge) and another about the way that components fit together to form a system (architectural knowledge). Thus is the Walkman example, architectural knowledge exists in reference to the way that every component interfaces with every other adjoining component. In comparison, our notion of information structures contain both component level knowledge and architectural level knowledge, but we focus upon a singular function within the complex product such that there are multiple clusters of knowledge built around operational functions.

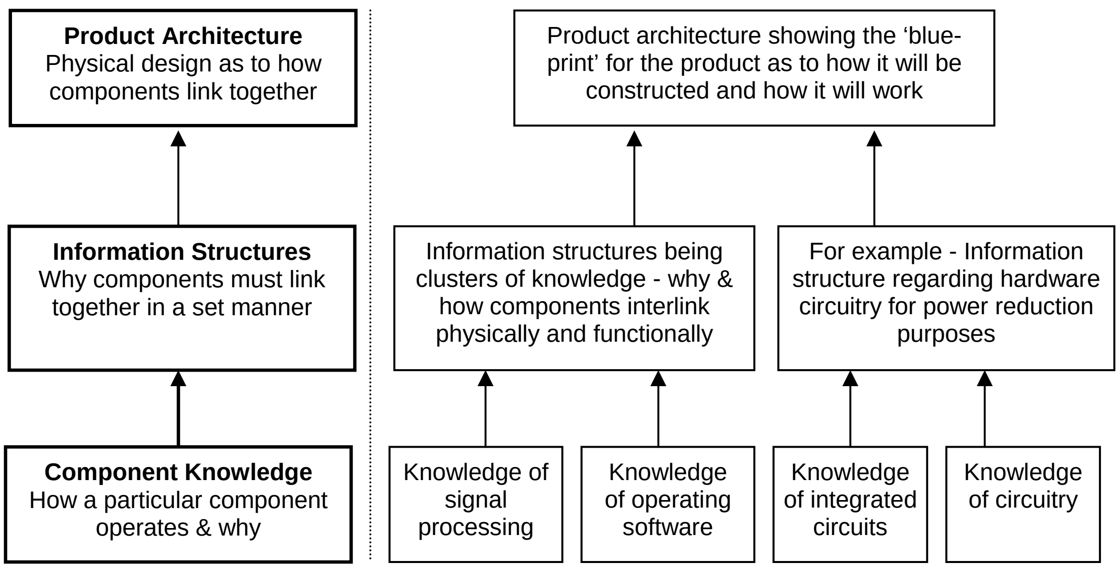

Figure 1: The relationship between component knowledge, information structures and product architectures.

Above the information structure lies the product architecture. This is the physical design manifestation of the information structure. Baldwin and Clark (1997: 86) define an architecture as ". . . what modules [components] will be part of the system and what their functions will be". For example, one of the basic advances that make mobile phones so successful relative to other mobile communications devices (e.g. CB radios) is the way that multiple signals are able to occupy the same time/space frequency (Agrawal and Sreenan, 1999). This knowledge is incorporated into an information structure covering how the mobile phone transmitter and operating software will interlink (forming part of the total information structure for the signal processing element of the mobile phone). That is, knowledge of how transmitters and mobile phone software work provides a knowledge structure of how they need to be integrated. The product architecture is the manifestation of this information structure, describing how components need to be integrated to create a 'blue-print' for the design of this part of the product, but by itself revealing nothing as to why the phone must be constructed in this manner. Continuing with the signal processing example, the architecture would detail an integrated system whereby the transmitted data for each call is given a unique sequence code allowing it to be distinguished from the data of other calls. However, the architecture does not indicate why this needs to occur, rather only how it occurs.

We see information structures as an analytical tool that will enable us to conceptualise and eventually group different elements of knowledge together based on technical grounds. In essence, we view information structures as clusters of knowledge that are comprised of component level knowledge and the knowledge of how these components operate interdependently. For example, an information structure may exist in relation to signal processing which is a cluster of knowledge about how all the components involved in signal processing operate and how they operate together to make for a functionally system.

It was proposed earlier that some knowledge that relates to product interfaces must be transferable such that complementary products and services can be developed. However, other elements of knowledge must be able to be protected within the firm as a basis for a competitive advantage. By deconstructing product architectures into information structures and component level knowledge, we are capable of now discussing clusters of knowledge in terms of common technical characteristics as being capable of being transferred or protected. We believe that this classification system for technical knowledge clusters is more useful within the context of our research for discussing the potential for knowledge diffusion or protection than some of the more traditional classification systems such as component versus architectural knowledge or the broader dichotomy of tacit versus explicit knowledge. As the knowledge that we are concerned with in this paper is technical in nature (such as interface specifications and communications protocols) most of the knowledge exists in fairly explicit forms. Thus we need to classify the different elements of knowledge in a way that covers the natural groupings of knowledge that are protected or purposely diffused. We suggest that deconstructing architectures into technical knowledge clusters is the first step to studying the knowledge management approaches used by Nokia and Ericsson.

RESEARCH METHOD

This research started from the observation that considerable work has been done in the area of the effect of network externalities and how such conditions affect industry level competitiveness. However, much of this research is grounded in industrial economics whereby the micro issues of how knowledge is managed such that architectures becomes either open or closed has been largely ignored. We believe that the role of the firm and their knowledge management systems are important. Within the mobile phone industry, what is immediately noticeable is that Nokia of Finland and Ericsson of Sweden form two of the three big players in the industry (with Motorola being the third major player). Nokia and Ericsson were virtually unheard of outside of their own countries prior to the 1980s yet they have outperformed almost all Japanese, other European and US mobile phone manufacturers. In contrast, firms such as NEC, Sony and Matsushita have failed within the industry to this point, even though the mobile phone is a product that fits very nicely into the broad Japanese capability of manufacturing products that are designed for consumers (as opposed to industrial users), are based upon microelectronics and are subject to miniaturization.

Our review of the literature to do with the existence of network externalities in cases where there are a variety of standards shows that the creation of a large installed base is critical in attracting further complementary products and services and thus providing a basis for becoming the dominant design. However, a review of the same literature, particularly the numerous case examples that were discussed, shows that the provision of an open architecture to allow complementary firms to enter into the broader support system for the product often leads to a loss of control of the technology and a corresponding loss of competitive position within the industry. For example, see the VHS versus Betamax wars in video recorders, the PC versus the Macintosh in computers, Sun versus Apollo workstations, RCA versus CBS television standards, 35mm versus 70mm film, and even the failings of both the Philips digital cassette versus the Sony Minidisk as formats to replace the CD with a recordable digital audio format. Thus we came to the conclusion that in many cases where network externalities are present, there is a need to both protect knowledge to maintain a competitive advantage and yet simultaneously diffuse elements of knowledge pertaining to the product throughout the industry so as to attain a large installed base. This became an assumption on which this research was based and all conclusions need to be read with this assumption in mind.

Given this assumption, our research question was:

How can knowledge be managed such that some components that make up the product architecture are accessible and transferable whereas other elements are highly protected within the firm?

The traditional tacit versus explicit dichotomy for knowledge classification was unlikely to assist in this process as the majority of the knowledge that we sought to investigate was of a technical nature and therefore tended to be relatively explicit. Hence our approach was to deconstruct the knowledge pertaining to the mobile phone around key technical areas. We would then assess the extent to which these various elements of knowledge were protected and how they were protected. In a similar approach, for those elements that were made open, we would review how these elements of knowledge were revealed to others within the industry.

We collected information about the types of knowledge that are required for the manufacture of mobile phones from the technical literature that exists and then supplemented this material with interviews with a number of senior people within both Nokia and Ericsson. In terms of reviewing how knowledge was protected and diffused within the industry we used these same interviews on location at Nokia and Ericsson.

A BRIEF HISTORY OF INTERNATIONAL DEVELOPMENTS IN MOBILE TELEPHONY

For mobile phone manufacturers everywhere, success in the initial analogue systems came about through producing products that were competitive in the attributes of size and weight. As the analogue systems were incapable of transmitting data (being based upon electrical impulses), there were no opportunities to integrate the phones with other products. Success in the industry therefore came down to reducing the size of the components in the phone, designing the internal circuitry of the phone to be more efficient in relation to power consumption, and working with battery manufacturers to develop more powerful, longer lasting batteries.

The multiplicity of analogue standards around the world made it difficult to conduct research and development activities for all standards present. Even though the analogue systems tended to differ primarily in the frequency used for transmission of signals, most large European countries (with the exception of the Nordic countries covered by NMT), Japan and the US all utilized different systems. The success of the NMT system in the Nordic countries in terms of the number of users, provided financial inflows to the local manufacturers to be able to move ahead in terms of design and weight. For example, in 1989 there were 75,000 mobile telephone subscribers in the Nordic countries as compared with 40,000 in the US Bell system and less than 10,000 each in Britain, Germany and France (Pulkinnen, 1997: 89). The Nordic manufacturers (Nokia and Ericsson) were then able to leverage their knowledge from the NMT market and develop phones for other markets. Between 1984 and 1988, Nokia for example, entered 20 different international markets (Pulkkinen, 1997).

While the first analogue systems were being rolled-out in the United States, the Nordic countries of Denmark, Finland, Iceland, Norway and Sweden were developing a new standard, NMT-450. While analogue in nature, the NMT standard was far more advanced than all other analogue standards in that it utilized digital switching technology and advanced base station design that accentuated the ability of smooth ‘handover’ for users while moving between cells. Developing these technologies facilitated research and development by the Nordic manufacturers in the development of digital type technologies, which put Nokia and Ericsson in a leading position when digital standards were adopted.

In Europe, the diversity of analogue standards created an inefficient system in terms of roaming and thus European operators and standards makers colluded to deliver a pan-European digital solution. The European Commission reserved frequency blocks across Europe further facilitating European roaming for users with one terminal. Thus the GSM 'second generation' digital standard gained broad acceptance throughout the European Union and was accepted as the European standard in 1987. Bekkers and Smits (1998: 40) note that all EU countries had at least two GSM networks operating in 1998, with the exception of Luxembourg. The standard was also accepted in a more limited fashion in the United States, the Asia-Pacific and other markets throughout the 1990s. As a digital format capable of transmitting both voice and data, the GSM standard provided much greater potential for complementary products to work with the mobile phone. As such, the second generation of mobile phones were able to able to provide the network connection for computers, to transfer faxes and emails. Advanced systems allowed for short message or email transfers without being linked to a computer.

In comparison, American mobile phone manufacturers were distracted by a multiplicity of analogue standards. Due to the relatively low take-up rate of mobile phones in the US and the problems that had occurred in respect of analogue systems, the US was a very late entrant into digital technology. Again a number of standards were to exist in conjunction with each other (D-AMPS, IS-95, GSM). Wooldridge (1999) notes the problems in the US market continue as there is competition between standards because of the fragmentation of the US market into regional licence areas (an artefact of the AT&T divestiture policies) and the continuation of 'receiving party pays' for mobile services. All of these complications have reduced economies of scale for all sections of the industry and have required further knowledge resources to be devoted to overcoming peripheral complications. The multiplicity of standards has made it difficult for complementary manufacturers to enter the industry and assist in the development of the mobile phones and associated products.

In Japan, a number of factors confounded the ability of producers and network operators to develop successful terminal equipment for second generation systems. First, mobile telephony in Japan was a tightly regulated monopoly for many years, and the network operator (NTT) had a market view of mobile telephony as a high-value service for a limited number of customers. Japanese producers were thus distracted by a home-market that demanded terminal equipment that could not be utilized elsewhere and a perception by both policy makers and NTT that mobile telephony was only to develop as a niche market. In addition, the economic conditions in Japan in the late 1980s (when digital standards were being developed) were far from supportive of the development of a new NTT based digital standard. The collapse of the "bubble economy" created economic turmoil among Japan's industrial conglomerates, many of who were key players in the national microelectronics industries. This in turn, tended to constrict their ability to dedicate resources to new technology R&D at a key time in the mobile industry's development.

Unlike analogue systems, success for manufacturers of digital mobile phones is dependent upon the quality of the phone (such as the number of features) and the extent of the complementary products and services. The importance of size and weight are becoming less important as phones take on additional features which actually require larger phones. For example, more phones are being released that have internet capabilities and new capabilities such as live video feeds will be introduced with the third generation systems. At this stage we move to deconstructing the product architecture behind the Nokia and Ericsson mobile phones as a way of beginning our review of how they have come to be so powerful within the above described context.

INFORMATION STRUCTURES IN MOBILE PHONES

We suggest that there are three relatively independent information structures that underlie the operation of each mobile phone. The first information structure is the air interface protocol. These have traditionally been set by relevant government agencies in particular countries or regions and are designed to ensure that the mobile telephone network can operate as a coherent whole. Once a standard is set by the government, Pulkinnen, (1997) suggests that it takes about two years to put in place the necessary infrastructure. Due to the need for multiple firms to be able to work with the standard, the information structure is codified (e.g. operates on the 900 Mhz band) and is completely accessible by potential industry players. Nokia and Ericsson were instrumental in having GSM adopted as a Pan-European standard due to their advanced research standing and their willingness to make GSM a non-proprietary standard.

The second information structure has to do with the way individual cellular mobile telephones operate within this protocol, such as signal processing, and transfer of data with complementary products such as computers and other ‘smart’ technology products. Within this paper we refer to this information structure as dealing with connectivity issues as it is centred around the way individual phones connect to other phones and interact with complementary products and services. Much of the second information structure is built around certain software elements and some hardware elements that include critical components that interface with complementary products and services.

The third information structure creates the functionality for the specific mobile phone. Much of the focus in this area was initially on developing ways to reduce the size and the weight of the phone. A more recent focus has been to increase the number of features and functions offered such as voice recognition dialling and diary functions. A diagrammatic presentation of these three information structures and examples of relevant component level knowledge are shown in Figure 2.

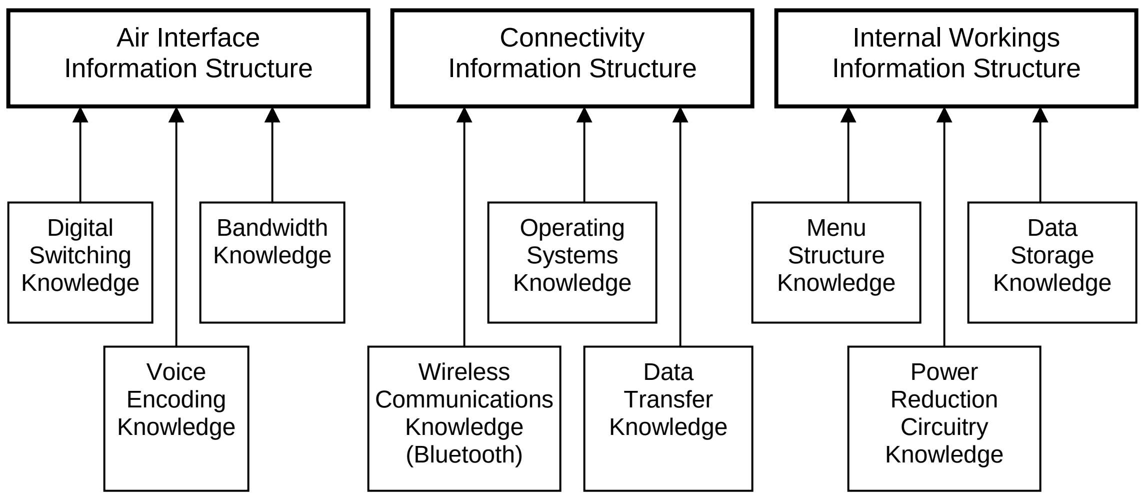

Figure 2: The three information structures and examples of component level knowledge that forms part of each information structure.

PROTECTING AND SHARING INFORMATION STRUCTURES

Air Interface Information Structures

The air interface protocol that is predominantly used by Nokia and Ericsson (GSM) is completely open in terms of the underlying knowledge being accessible by others. Technical specifications exist in the form of manuals that can be accessed by all those who are presently in, or wish to enter the industry. This openness was part of the process of having GSM adopted as the Pan-European standard. Paetsch (1994: 287) comments how “the GSM standard itself is an open nonproprietary-standard, which means that not just the air interface is specified but all interconnections between the base station and network subsystems".

Nokia and Ericsson were key developers of the GSM standard. Building from their experience with the advanced analogue standard, NMT-450 (featuring digital switches and other advances), both firms conducted much of the R&D that would later form the basis for GSM. Once GSM became operational, both firms pushed the European Union to accept GSM as a European second generation digital standard. Part of this process was making GSM completely open such that any firm could access all of the technical specifications.

It is interesting to note how this approach differs to that used by the developers of other air interface protocols. GSM is based upon Time Division Multiple Access (TDMA) whereby a given bandwidth is divided in eight call timeslots. The other main approach is to code multiple calls within a bandwidth (Call Division Multiple Access – CDMA). However, whilst CDMA systems are also generally open (with the exception of some second generation Japanese systems), users of CDMA technology have to pay license fees. For example, Ericsson completed a deal with the owner of the technology, Qualcomm, such that it could enter the CDMA market. Due to these difficulties in accessing CDMA technology there is a significant gap between the technologies available for TDMA networks such as GSM and CDMA networks. For example, Nokia has already released a phone with a chipset that will enable 18 days of standby time for GSM networks. A similar product for CDMA networks is likely to be more than a year away.

In addition, as the International Telecommunications Union tries to lead the industry into a position of having a single communications standard for third generation systems around the world, there is a general level of acceptance that CDMA technology is superior to that of TDMA technology. However, Nokia and Ericsson are both pushing for the wideband version to be adopted (W-CDMA) as adoption of the CDMA standard would require royalty payments to be made to intellectual property owners in the US. To assist them in their fight for W-CDMA, Nokia and Ericsson are working with Japan's leading provider in relation to networks, DoCoMo such that there is a united front pushing for a completely free and open standard.

The move to make GSM a completely open standard by Nokia and Ericsson was, with the benefit of hindsight, a wise one. Systems using the North American AMPS analogue standard (or related standards such as TACS) in 1996 far outnumbered those using the Nordic NMT or other analogue standards (103 nations versus 39), but where digital standards have been adopted, GSM outnumbers CDMA networks, 101 nations to three (Funk, 1998: 423).

Connectivity Information Structure

The second information structure has to do with operating the mobile phone within the established air interface protocol and thus it is here that there are enormous opportunities in the area of complementary products and services. Much of this information structure is built around component level knowledge to do with various software elements. There are also some hardware knowledge elements for specific pieces of hardware that interface with complementary products. In general the approach taken by Nokia and Ericsson has been one of collaboration with selected partners. For example, Nokia has already developed technologies with complementary firms to allow them to purchase items from sources such as vending machines and on public transport systems, with the charge going onto the monthly bill (Wooldridge, 1999).

More advanced wireless technologies, where data is actually exchanged between devices (as opposed to simply sending data as in the case of payment systems) is being developed within the Bluetooth Project. Bluetooth is a wireless technology that seeks to replace the wires and cables between computers and other electronic devices in homes and offices with a local broadband wireless network. Bluetooth was one of many potential technological solutions and Ericsson sought the support of other large backers to develop a critical mass of support.

Initially begun with five members, Ericsson initiated a "Special Interest Group" (SIG) which now comprises members from mobile telecommunications, IT hardware and software, media, medical and industrial sectors. All members of the SIG have access to necessary protocols to facilitate the development of hardware and software for Bluetooth applications. Broader control of central elements of the standard (for example, changes in the protocol) is exercised by a "Promoter Group" (PG), currently comprising 3Com, Ericsson, Intel, IBM, Lucent, Microsoft, Motorola, Nokia and Toshiba. The cooperative nature of the PG and SIG is the result of an early strategic decision by early developers of the technology – and most notably Ericsson. While this firm was a founder of the Bluetooth consortium with Nokia, IBM, Intel and Toshiba, it was Ericsson that adopted the early technological champion role, undertaking essential early R&D which saw Bluetooth emerge from a competitive environment as the preferred wireless connectivity standard. Today Ericsson has alliances with Microsoft and Qualcomm to develop both software and hardware for Bluetooth applications. Similarly, Nokia has entered into an alliance with Japan's Fuji to develop software for the transmission of digital photographs.

The relative openness of information structures to do with connectivity can also be seen in the area of software. Both Nokia and Ericsson are moving away from proprietary systems. Most recently they have adopted a Java language based operating system by Psion, a provider of operating systems for personal communicators (devices that are bringing together mobile phone and computing technology) (Berendt, 1998: 30). Psion's Java enabled operating system, Symbian is licensed to the big three in the industry, Ericsson, Motorola and Nokia. The adoption of Java as the language for the operating standard of personal communicators will allow further innovative programmers to contribute to product and industry development through the introduction of innovative 'applets'. Mobile phone producers, in utilizing Java, have ensured that providers of complementary products and services can develop their products (or services) in the knowledge that 'plug and play' capabilities can be relatively easily attained.

In addition, rather than just hope for complementary products to emerge from other firms, Nokia and Ericsson have specifically encouraged cooperation between large and small manufacturers at the industry level within the Nordic region. This has been further encouraged by explicit government policies in both Sweden, and more especially Finland, where the government helped establish technology parks in areas like Spinno, near Helsinki (Autio and Kloftsen, 1998). These parks, anchored by central players in the industry such as Nokia, saw the development of a range of small support firms with strong links to the university sector and government funding agencies. These small firms have since been responsible for many of the innovative components associated with mobile phones.

The information structures that were concerned with connectivity were generally far less accessible than those pertaining to the air interface protocols. However, due to the need for complementary products and services, both Nokia and Ericsson went to considerable lengths to establish collaborative relationships with appropriate partners. The Java based operating systems and Bluetooth projects were relatively open in terms of the information structures. At the other end of the scale, some of their joint ventures with partners such as Siemans and Alcatel to produce enhanced communications performance through projects such as EDGE

(Enhanced Data for GSM Evolution) and Tiphon are far less open except in terms of the final protocols that affect the actual operation of the phone.

Internal Workings Information Structure

The third information structure covers the internal workings of the phones and is relatively independent of any complementary products or services. It was here that there was the lowest level of accessibility of the underlying component level knowledge by other firms. There were some example of joint ventures such as in the case of batteries and speakers (e.g Ericsson with Bang and Oulfsen). In addition, the existence of a Java based operating system makes it possible for additional features to do with menus and data storage options to be easily incorporated. However, in general, Nokia and Ericsson developed and controlled most of the underlying knowledge that forms part of this information structure.

It is interesting to note that while this information structure is the least open of all, and by implication, the most protected, the elements that derive from this information structure are the easiest to copy. It is for this reason that new and upgraded mobile phones are constantly being released. Nokia for example, uses a relatively modular approach to the way it introduces innovations that relate to this information structure. Their new 7110 model has an augmented display that is 80% larger than the 6110 model and incorporates a scroll button, but otherwise it contains most of the 6110 features. The 3210 similarly recycles the entire menu structure of the 5110, instead introducing some new styling and reducing the overall weight. Although considered to be technologically behind Nokia, Ericsson follows a similar approach with their basic design remaining relatively constant, but each successive model introduces some new features.

The knowledge that underlies many of the advances that fall within this information structure would not seem to be embedded within organizational routines or requiring specialized assets that would make it difficult to copy. Rather it is simply the pace of development that keeps rivals at bay. The second tier mobile phone manufacturers (e.g. Alcatel, Philips, Siemans, Sony, NEC) have an option to either try and copy the functionality of Nokia or Ericsson phones or to try and develop and innovative feature themselves. To copy existing functions is generally not seen as a winning strategy as whilst new models used to come out every two years, the adoption of a modular approach is ensuring that there are now far more regular new product offerings. Thus a copy strategy will still see the second tier players falling behind and most likely will be unable to achieve the necessary economies of scale to effectively compete on price. Thus, innovations are generally eventually copied, but the constant upgrading of component level knowledge allows Nokia and Ericsson to regularly release new innovative models. The protection of this information structure tends to be based more around simply developing at a faster rate than competitors rather than implementing specific protection systems or through trying to embed critical knowledge components within the organization.

DISCUSSION AND CONCLUSION

The case of Nokia and Ericsson coming to dominate the mobile phone manufacturing industry (along with Motorola) is an excellent example of carefully managing information structures such that some knowledge is protected and other knowledge is purposely diffused. Starting with the GSM standard, the complete openness of the air interface protocol allowed multiple firms in all areas of the industry to become involved. The result is that the GSM standard has been adopted in 101 nations around the world (versus three for the CDMA standard). This has provided a very large installed base for all those firms that create products or services for the industry within the GSM standard.

While the domination of the GSM standard has the potential to benefit Nokia and Ericsson as two of the key developers of the technology, the openness of the standard has meant that any longer term sustainable advantages must derive from a superior product and more complementary products and services relative to other GSM oriented competitors. It is here that the true value of keeping some technical knowledge embedded and making other elements explicit, is best seen. The use of strategic alliances to rapidly develop complementary products and services has meant sharing elements of technical knowledge with these selected partners. Most of this knowledge has to do with interface specifications and software operation, but it does mean that there is the potential for proprietary knowledge to slowly diffuse across the industry. Serious knowledge leakage has been minimized by selecting appropriate partners and through simply keeping the rate of change so high that by the time this knowledge can be incorporated into competitors' products, it is outdated.

The use of some knowledge being more open and accessible to a range of firms is best seen in the use of a Java based operating systems and a defined protocol for wireless communications (Bluetooth). These less protected elements of the information structure keep the barriers to entry into complementary segments of the industry low and thus allow for the involvement of other firms (such as those within the technology parks in Finland) where the alliances are not as closely selected or monitored. This trend of developing alliances continues today on a global scale with the Nordic phone manufacturers having extensive linkages with firms in Silicon Valley.

Those elements of knowledge that do not interface with other products or services and are not required for the development of complementary products and services are generally protected wherever possible. For example, Nokia exercises tight control over their knowledge of power reduction circuitry, creating a situation whereby competitors' phones are unable to offer the same level of functionality for the same weight and are at a distinct disadvantage in the market place. This type of knowledge is of key importance given the many of the complementary products and services (even though often developed by Nokia) are available to all users of GSM mobile phones (such as using the phone as a smart card technology for purchasing goods or services).

Most interestingly, whilst the GSM standard is completely open, Nokia and Ericsson have not lost their competitive position in the industry in the same way that Matsushita became just another video recorder manufacturer, or IBM became just one of many PC manufacturers. They have managed to avoid this pitfall that often seems to accompany the developers of standards largely because they have managed to keep at least some of the knowledge that underlies their competitive position protected. In addition, where they have shared knowledge as a way of encouraging the development of complementary products and services, they have wherever possible chosen their alliance partner carefully and only in two situations have they made parts of their 'connectivity' information structure open.

In reviewing how some knowledge has been actively diffused throughout the industry and other elements have been heavily protected, the notion of information structures has been particularly useful. By being able to systematically cluster knowledge into key groupings based upon the interdependence of key components, we were able to structure our review of how different clusters of knowledge were managed using a schema that was appropriate for this industry. The information structures approach would seem to have advantages over Henderson and Clark's (1990) architectural and component level knowledge concept as their approach does not adequately allow for clustering of technical knowledge based around selected functionality.

In conclusion, the mobile phone industry today is one where compatibility and network externalities are becoming more and more important. This has led to some standardization. However, Nokia and Ericsson, as prime proponents of the GSM standard have not lost their competitive position within the industry. We have been able to show how they have managed various components of their knowledge through the use of information structures as clusters of technical knowledge based around the operation of interdependent components executing particular functions.

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