Cumulative Innovation and the Making

of a Transformative Complex Product System

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Abstract

Dominant theories of technological progress focus on innovation carried out by numerous competing firms during crucial parts of the technology life cycle. Industries producing complex product systems such as flight simulators are seen as partial exceptions, but they are rarely portrayed as central to progress. There is, however, evidence that the construction of some large complex product systems – for example, systems of very large retail firms – may have produced substantial technological progress centralized in single companies. To explore how such progress can occur, this study examined the process of system creation in a medical devices firm whose products caused highly toxic side effects in the mid-1980s but whose evolved system in the 2000s had become dramatically safer with higher cure rates. The data shows a market-oriented, cumulative process of transformation. The firm introduced many significant but not individually transformational system elements, and the evolving elements were linked through intense work on interfaces among them and on interfaces for end users. Examination of much more fragmentary data on the creation of transformative complex product systems at two large retail firms suggests they generally followed a similar pattern. Based on this data, a preliminary theory of technological change through creation of transformative complex product systems is proposed.

Cumulative Innovation in the Making

of a Transformative Complex Product System

Dominant theories of technological progress focus on decentralized innovation. Technologies go through a life cycle in which competing firms are numerous during critical periods (Anderson & Tushman, 1990; Covin & Slevin, 1990; Moore, 1991). Industries producing complex product systems such as flight simulators and aircraft engines can be partial exceptions because of their higher barriers to entry and exit and their differing institutional structures (Hobday, Rush & Tidd, 2000; Miller, Hobday, Lerous-Demers & Olleros, 1995; Rosenkopf & Tushman, 1998). However, complex product systems are rarely portrayed as central to overall technological progress.

There is, however, reason to believe that some important progress does not follow the decentralized path. The building of a large complex product system may produce substantial progress largely centralized in one firm. Such systems can be highly beneficial and profitable. For example, evidence suggests the complex product systems Wal-Mart created in the late 20th Century were drivers of the accelerated productivity growth the U.S. experienced from 1995 to 2000 (Johnson, 2002; Federal Reserve Bank of Chicago, 2004). If the arguments about Walmart in the late 20th Century are plausible, perhaps construction of a complex product system in a single firm can contribute crucially to technological advance.

Little systematic knowledge seems to exist, however, on how such technologically transformative complex product systems can be created. Researchers have examined innovation processes in firms producing complex product systems, but in general it suggests such innovation is a matter of many related organizations negotiating how new products will emerge (Hobday et al, 2000; Miller et al, 1995). Large complex negotiations are not noted for producing the radical technological progress reported in the Wal-Mart case.

To begin to fill the gap in our knowledge of the emergence of transformative complex product systems, this paper examines the creation of one such system. It compares the data from this system with more fragmentary information on two other technologically significant complex product systems. It uses this information to develop preliminary elements of a theory of how technologically transformative complex product systems can come into existence.

The core of the research is a study of the process by which the Medical division of Varian Associates Inc. developed an advanced system to destroy cancerous tumors by radiation while protecting healthy tissue. As will be discussed below, this was an extensive undertaking. Varian's competitors in medical linear accelerators did not attempt to produce such a system as early as Varian and dropped out of the market as elements of Varian's system became functional. Others – including academics, new firms, and a joint technology development program of the Nordic countries – played roles in creating the technology embodied in the system, but Varian developed by far the most widely used system and the success of the No. 2 firm in the industry involved purchase of a startup created by former Varian employees. The complex product systems analyzed here were responsible for dramatic improvement in doctors' ability to cure cancer (Alicikus et al, 2011; Zalefsky & Deasy, 2013).

This paper is structured as follows: First a literature review examines research on complex product systems and knowledge about creation of complex product systems that seem to have produced dramatic technological progress. Next, the method of the study and the nature of the process being examined are described. The results of the examination are presented. These results are compared with existing literature. Based on this, a tentative theory of radical innovation through creation of complex product systems is presented. A conclusion summarizes results, discusses limitations, and suggests possible further research.

Literature Review: Complex Product Systems and Transformative Innovation

The complex product systems (CoPS) literature focuses on systems created by firms that specialize in building large systems. The business systems of a firm like Walmart clearly fulfill the standard definitions of complex product systems in the literature, however. Hobday, Rush and Tidd (2000) define CoPS as "high cost, technology-intensive, customized, capital goods, systems, networks, control units, software packages, constructs and services." Research has examined flight simulators (Miller, Hobday, Lerous-Demers & Olleros, 1995; Rosenkopf & Tushman, 1998); aircraft engine control systems (Prencipe, 2000); turboprop engines (Bonaccorsi & Giuri, 2000), and offshore oil projects (Barlow, 2000). For businesses that create such systems over and over the "project-based organization" structure is recommended. The literature does not seem to tell, however, how radical technological advance can occur through creation of these systems.

Technologically transformative complex product systems

The existing scholarly literature may not be capturing the full importance of complex product systems. Much popular literature, financial journalism, biography, teaching cases, and consulting literature reports on large complex product systems that have made dramatic contributions in ways little addressed in scholarly literature.

Consider the system whose creation was led by Sam Walton at Walmart and that led by Jeff Bezos at Amazon. Substantial benefits are reported in work that, while not scholarly research, seems to have been carried out with some care. See Foley, Bradley and Ghemawat (1994) for Walmart and Stone (2013) for Amazon. The systems appear to perform economically important tasks that were not previously done as well. The magnitude of the achievements is clearly unusual. Details need validation through careful study. However, financial returns have been indisputable.

The systems that support Walmart's and Amazon's businesses are clearly complex product systems according to Hobday et al's definition. However, these companies are not in the business of creating such systems. Rather, they created the systems for their own businesses. Walmart's case, there is evidence that in addition to returns for the creating firm there were large returns to the economy as a whole as other firms copied it (Federal Reserve Bank of Chicago, 2004).

Existing literature does not give a clear picture of how the processes of creating Walmart's and Amazon's systems compared to the creation of complex product the systems studied in the scholarly literature. The popular, biographical, and financial literature on Walmart (Bjelland & Wood, 2015; Soderquist, 2005; Walton & Huey, 1992) and Amazon (Stone, 2013) is enough, however, to suggest that the process of creating their systems may differ from processes described in standard literature on strategic management of information systems (Grant, Hackney & Edgar, 2010). The Walmart and Amazon literature describes pursuit of a largely consistent strategy over decades; this is unlike processes described in conventional literature on strategic management of information systems.

It is thus worthwhile to study processes by which transformative complex product systems may be created. This research is exploratory. It seeks to begin to understand processes by which some organizations produce complex product systems that radically advance technology.

Method

Varian Medical Systems was selected as a research site and Varian's process of creating "intensity modulated radiation therapy" and "image guided radiation therapy" was selected as a focal case. At the time when the elements studied here began, the organization was a division within Varian Associates Inc. Varian Associates' 1981 annual report indicated the division had sales of $50 million and $6 million in profit at the beginning of the period studied. Varian Medical Systems had sales of $2.07 billion and profit of $279 million at the end of the period in 2008. Headquartered in Palo Alto, Calif., it had 4,900 employees in 2008.

The Medical division, Varian Medical Systems, and their complex product system process were believed to be an appropriate organization and process to study in pursuit of answers to the above questions. The system Varian had created to destroy cancer while sparing healthy tissue was extremely complex but probably not as complex as the most complex product systems (such as those of Walmart and Amazon). It seemed possible that a research study could achieve a reasonable understanding of how it came into existence and that understanding might shed light on the phenomenon of organizations creating complex product systems that advance technology radically.

Varian Associates was founded in 1948 to leverage the development of the klystron, a vacuum tube developed in the 1930s by the brothers Sigurd and Russell Varian together with several Stanford University professors. Both the social returns to the creation of Varian's medical system (curing of millions of cancers while greatly reducing side effects) and the economic returns (creation of a firm with $10 billion in market value from a division that had merely $50 million a year in sales) were clearly high. Unpublished writings by key figures aided the study. The former chief executive who had led the organization through the largest part of period had written an unpublished memoir. Eventually two other senior executives wrote helpful reports. The executives did not read each other's writings, and they differed significantly. However, the fact that some key informant statements were in writing helped in triangulation.

Varian Medical's Technology

In 1954 Stanford physics professor Edward Ginzton, one of the founders of Varian Associates, collaborated with Henry Kaplan of Stanford Medical School to build a linear accelerator on a movable base, making it possible to aim the accelerator more precisely towards cancer tumors (Ginzton et al 1985; Jacobs, 2010). The accelerator was powerful enough to destroy most cancers. However, cancer-destroying radiation also damaged healthy tissue. It could and sometimes did prove toxic.

By the 1980s, radiation oncology was an established medical specialty. Varian and several competitors sold medical linear accelerators, and reliable protocols existed for treating a few cancers. However, radiation could reliably cure relatively few types (Jacobs, 2010). Doctors sought to protect healthy tissue with heavy metal blocks placed between the beam and the body, but still doses that might destroy disease were often considered too dangerous to administer.

In the early 1990s, Varian introduced a linear accelerator with a motorized multi-leaf collimator, a device that made shaping the beam easier, and electronic imaging that made aiming the beam at its target more precise. CT scanners and treatment planning (mostly from other vendors) allowed what doctors called "3D conformal therapy." Studies showed higher cure rates and declines in toxicity (Zalefsky et al, 1998). Siemens, Philips, and General Electric continued to provide difficult competition, however. They introduced their own multileaf collimators.

In the mid 1990s, the startup Nomos introduced an accelerator said to calculate and deliver doses more precisely and easily, allowing greater doses to thicker parts of tumors and limiting doses to sensitive organs, a process called "intensity modulated radiation therapy." Varian introduced its intensity modulated radiation therapy products soon after. In the early 2000s it introduced better imaging, better treatment planning software, and image guidance that ensured extremely precise patient positioning. By 2010, Siemens, Philips, General Electric, and Nomos had dropped out of the market. Philips sold its business, based partially on a firm started by former Varian employees, to the Swedish firm Elekta, which continues to compete successfully today. However, Varian Medical estimates in its 2016 annual report that of 13,000 accelerators currently operating in the world, 7,500 or 58% are Varian machines. Recent studies show the largely Varian-dominated intensity-modulated radiation therapy market of the 2000s provided substantially better cure rates and less toxicity than "conformal" therapy in the competitive market of the 1990s. (Alicikus et al, 2011; Michalsky et al, 2013; Zalefsky & Deasy, 2013)

Data Collection

Case study methods of Yin (2014) and Eisenhardt (1989) were followed. Data collection was by interview, gathering of external and to a lesser extent internal documents, and direct observation of Varian offices and factory and of a leading medical center hospital.

Fifty-four hours of interviews were conducted with 12 current and former Varian employees and an additional 12 hours with 11 customers and other medical people and one competitor. Retrospective reports can be inaccurate (Golden, 1992), but to maximize reliability a variety of different leaders with different points of view were interviewed and the reports checked for plausibility against each other and against contemporaneous published information. Interviewees frequently provided apparently contradictory information; repeated contacts, often carried out after reviewing contemporaneous published reports, seemed to establish a credible narrative on most but not all issues. Interviewees included the most senior executives, a key executive known for pushing for better performance, and executives involved in implementing innovation processes. Also included were senior members of the engineering department, which lost centrality during the process under study, and the head of the first team to achieve technological success outside the engineering department (an individual no longer employed by Varian). It seemed plausible that the biases of the selected informants might offset each other (Huber & Power, 1985).

Because informants had experience with different parts of a complex process, no standard interview protocol could be used. Instead, a list of objectives was developed prior to each interview and then a list of questions to be covered to achieve the objectives was created. Because so little of the internal dynamics of the process appeared in documentation that could be read beforehand, it was often necessary to depart from prepared questions. Interviews were recorded. I made extensive notes. Key interviews were transcribed and notes, recordings and transcriptions were used together to ensure accurate reporting.

To ensure reliable understanding of the processes, separate chronologies were created from interviews with each of the key Varian participants. Chronologies were compared to triangulate and ensure accurate understanding of events. A separate large file was created with all data that seemed potentially significant organized chronologically. Finally, basic chronological outlines were created that summarized the evolving understanding of the core processes. Drafts of preliminary work were shared so direct participants could correct understandings.

To partially compensate for limitation of focusing on a single case in the core research, the Discussion section will discuss the extent to which popular, biographical, and financial reports on the creation of other large complex technology systems may provide additional credible data and how that data compares to the findings of this study.

Results

The elements that contributed to the creation of Varian Medical's complex product system for destroying cancerous tumors can be understood in terms of eleven interlocking processes. Figure 1 diagrams those processes. The descriptions below focus first on processes driven by key personnel, especially three key individuals. Then six processes related to technology development and introduction are discussed. To focus on processes rather than individuals, individuals are identified by their initials only.

Insert Figure 1 about here.

Key Personnel Actions

Processes driven by three individuals and the engineering department need to be understood.

Process 1 – A salesman becomes general manager and seeks to drive change. The creation of Varian Medical's complex system for cancer treatment began not with company engineers or top executives but with individuals who had been hired as salespeople. Varian often hired salespeople with advanced degrees in the sciences. R.L. was hired in 1968. He held a Ph.D. in chemistry. He rebelled against Varian's engineering-driven culture, insisting the engineers who ran the division should focus more on customer needs in product design. (See examples of data at the end of this subsection.) At the same time, he was also able to work closely with engineers, sharing a patent for a filter designed to prevent skin irritation from cancer treatment. Varian executives promoted him first to sales manager, then assistant general manager, then general manager in 1986.

As general manager, he sought to change work organization from hierarchical by function to cross-functional teams. He said he had a sense of the strategic priorities that would drive Varian through the 90s when he made his first speech to Medical division employees in 1986, but he had difficulty articulating it. (See "A New View of the Company," below.) As a large effort to redesign the company's most advanced product seemed to be floundering (Process 3), an impressive junior computer programmer told R.L. he could not effectively work within Engineering. R.L. had him create a "skunk works" reporting directly to R.L. himself. The skunk works built the first computerized controller for Varian accelerators. The project succeeded; the architecture is still used in Varian products today.

Examples of data.

> "I got into red-faced arguments with engineers who wanted to include features the customers didn't need, simply because these features represented 'good engineering'.... In one noteworthy disagreement with an

engineer, I put my fist through a fiber-board wall. In another, I pounded on the glass top of my desk and shattered it. " – R.L.

> "Cross functional teams solved a lot o things that were just stuck for years. There were parts of the machine that you just couldn't get anybody to work on. Then suddenly you could." – T.G.

Process 2 – Technically trained salesman pushes long-term development. J.F. was hired as a salesman in the early 1970s. He had a Ph.D. in physics. Like R.L., he developed close relations with the engineers who designed the products. Meanwhile, he read scientific literature for possible solutions to problems that his medical doctor clients had in treating patients. Among the publications was a proposal for a "multileaf collimator," a device for shaping the accelerator's beam, proposed by Shinji Takahashi in Japan (See Doi, Morita, Sakuma & Takahashi, 2012.) As a successful salesperson who called on Japanese customers, J.F. was able to visit Japan and learn about the device. He brought Japanese knowledgeable about the collimator to speak to users groups in the U.S. and discussed it with leading doctors at medical centers, some of whom thought it might represent a partial solution to toxicity. J.F. said he began "conspiring" with Z.F., one of the doctors, to get Varian to create a motorized, computer controlled version of the collimator.

Meanwhile, in sales calls, he noted a group of add-on products that small firms were selling to enhance linear accelerators. He began campaigning inside Varian for the firm to include the capabilities of the add-ons in its offering. JF was promoted to be one of two senior vice presidents overseeing North American sales. In the mid 1980s he asked to be put in charge of Varian's international business, at the time a small part of revenues. He helped international business to expand and at the same time found additional technology outside the U.S. that was useful to Varian.

> "I never looked at myself as a sales guy. I looked at myself as a person who could make a living off sales while doing what he really wanted to do, which was physics and science. There's a great deal of salesmanship in science. The photon needed to be sold 1905. Albert Einstein was a sales guy." – J.F.

> Regarding the promotion of radical change: "There is a huge counterforce in business who would say our job is to find what the market wants and build it. We had just a few people who said, 'Here's something that's revolutionary, let's go do that.' Then our job was to find some people we could reach out to and say, 'Here's something we could do,' that would get them very excited. – J.F.

> "[J.F.] was they guy who pushed dynamic wedging. Ahh, he was in my [expletive] office every day, 'We've got to have dynamic wedging; we've got to have dynamic wedging.'" – T.G.

> "As for J.F., we were just lucky. There are not many sales guys who have his vision and persistence" – T.G.

Process 3 – A failed re-design. In the early 1980s, engineering leaders persuaded Varian executives, including R.L. who was assistant general manager, to fund design of a totally new high-energy linear accelerator. The effort was plagued with problems and missed deadlines. Executives killed it after five years. From then till the second decade of the 21st Century, Varian made engineering improvements to its core machine incrementally.

> "By 1985, we had spent $11M, over five times the original engineering estimate, and were still at least five years away from completion of the

product. We killed the project. Later and fortuitously, we were able to use many of the designs intended for [the new product] on other machines." –R.L.

Process 4 – A service manager handles operations and development. T.G. came to Varian with a bachelor's degree in electrical engineering and computer science and experience in service at another electronics firm. He worked in service on a pioneering Varian product that failed in competition with larger firms. He was promoted first to service manager for the whole Medical division then to general manager. In the 1990s R.L. was general manager dealing with external relations and T.G. dealing with internal workings. He remained in charge of internal operations until 2006, when he was promoted to chief executive of the now-independent Varian Medical Systems.

Soon after he was promoted to general manager, T.G. read a variety of business books including Porter (1985). This led him to conduct a Strengths-Weaknesses-Opportunities-Threat (SWOT) Analysis. An obvious weakness was that the Medical division was not highly profitable based on standard financial ratios. A threat was that the larger firms that also made linear accelerators could afford to do substantial development on competing features. Perhaps balancing these, Varian believed its engineering and service were superior. Based on the intense competition that sharply limited the prices the company could charge, however, T.G. concluded that the Medical division's strengths were not very important to its customers, and its survival was threatened.

He turned to the engineering department for ideas and was told it could only promise incremental improvements. T.G. and other leaders felt the situation was serious. (Varian later realized that competitors had not been investing in new features. Price competition, however, was real.)

> "All of my competitors were focused on cost reduction and price reduction. They were all low price competitors. I had read my Michael Porter. I knew I couldn't be the low price leader. I wanted to be leader with the differentiation." – T.G.

Processes working together: High-level listening to customers who had dreams. In Figure 1, R.L.'s rise and effort to serve as a change-oriented general manager is treated as Process 1 and J.F.'s effort to build the physics career he wanted through sales is treated as Process 2. Of course the two worked together many times. However, these two efforts came together especially importantly in customer meetings. Varian salesmen and executives had held regular users' meetings since at least 1972. In addition, R.L. had been one of a few industry leaders invited to an annual meeting of top doctors who liked to ski at Vail, Colo., each year. Varian created a highest-level users' meeting patterned in part on the Vail group. R.L. and J.F. recruited a group of radiologists they considered most visionary, principally from university medical centers, to meet top Varian executives and product designers at top resorts at Varian's expense. (It was legal to do this at the time.)

The group, called the RT -2000 (Radiation Therapy-2000) committee, did not keep minutes or issue reports. Nonetheless, all participants interviewed agreed it was important. J.F. and some of the medical center doctors found the meetings a good opportunity to campaign for product ideas they had long supported.

> "Some members of the RT-2000 committee felt that unless the MLC could change shape dynamically as the machine rotated, the clinical benefits would not justify the high cost… Others, including myself, felt that this project would be incredibly complex and we should keep it as simple as possible to assure safety for patients and a reasonable time to market." – R.L. (Varian general manager)
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> Regarding an argument with RL about the possibility of a dynamic multileaf collimeter: "[RL] said 'There is no way that we can use it if it's moving during treatment. How can you quality assure it?' So I asked him, 'What do you do when you fly from New York to San Francisco? What does the pilot do? (The pilot relies heavily on computer navigation.) You always land on the right runway. You've got to trust the computer.' That type of confrontation occurred all the time." - ZF, leading university medical center physician.

Processes working together: A new view of the company. Processes 1, 2, and 4 – the work of R.L, J.F., and T.G. – and the work of other leaders all came together in a re-thinking of the company's strategy. Retrospectively, Medical division leaders say the company adopted a new vision in the late 1980s, and it is clear their thinking evolved at that time. The new vision, leaders say, involved thinking of the company as a global rather than principally a North American business and as one had to develop a more comprehensive portfolio of radiotherapy equipment products. However, there is reason to believe the understanding may have been less clear than the world 'vision' may imply.

RL said that after he spoke for 45 minutes to employees about strategy, they still could not describe the strategy. Therefore, he adopted a brief but by no means comprehensive slogan to describe it. (See quotation.) Several years later, in 1992, , the company adopted a more precise, actionable plan, stating it would pursue "integrated, networked, conformal radiation therapy."

> "In my first speech to employees in 1986, I delivered a rigorous 45-minute analysis…. Shortly thereafter, an employee survey indicated that there was a poor understanding of our strategy…. Finally, it dawned on me that everything we were doing was focused on curing more cancer. What was needed was not a 45 minute talk, but a simple, true, and inspirational sentence, a vision: 'We are here to cure more cancer.'" –R.L.

Process 5 – Coordinated upgrades. Product upgrade management had been challenging for the Medical division from at least the 1970s. T.G. had learned about managing upgrades at another electronics firm. He proved capable of managing them when promoted to service manager and general manager, as they became more and more complex. This mechanism helped elements of Varian's systems to work together smoothly. In interviews, leading radiation oncologists generally spoke highly of Varian's upgrade processes, though one said that while the firm had made radiation therapy vastly more powerful both Varian and the radiation oncology profession had not done as much as needed to ensure quality control in community hospitals.

> "System architects would analyze upcoming feature changes, and would design upcoming releases on all products to work together. Then we would test extensively for bugs in interactions. If a customer wanted a new feature on a product, they needed to upgrade the whole system. We would hold giant meetings to work out how to handle all these interactions." –T.G.

Medical Division Technology Development Processes

As a result of the processes above, in the 1990s Varian sought to introduce significant innovations. Initially, it struggled. An alliance existed between Varian and leading university radiation oncologists who participated in the RT-2000 committee. However, Varian does not appear to have achieved strong differentiation until the late in the decade.

Separate initiatives addressed distinct opportunities to improve radiation therapy. There were large efforts at coordination, especially associated with upgrades. Sections below review the processes through which four important technologies evolved together with key support processes.

Process 6 – Simulators. The first products the Medical division sold other than linear accelerators were simulators, machines that used lower radiation-level diagnostic x-rays to allow doctors to simulate the effects of different approaches to treatment. Varian had entered this business in the early 1980s because it found the leading U.S. simulator company uncooperative when hospitals wanted to buy an accelerator and simulator together. It purchased a small British simulator company andian had its engineering staff work with the British unit to upgrade performance and keep up with rapid advances in related technology.

> "T.Co. didn't look like much – originally the building they were in had a thatched roof. But we completed the acquisition…. Then we fixed it up." – J.F.

Processes 7 and 8 – Varian multileaf collimator and a startup's competition.

T.G. and Varian engineers participating in the committee had Varian Engineering begin work on a multileaf collimator as the RT-2000 committee debated it. The committee reached consensus that Varian should start with a machine whose leaves were motorized but would not move during rotation. Varian introduced it to great interest from radiation oncologists. Then J.F. reported Japanese hospitals wanted a multileaf collimator could that change shape while rotating. After 18 months of effort engineering produced reliable software. A startup, N., introduced its own multileaf collimator and software. Varian then introduced the dynamic multileaf collimator and software into its U.S. accelerator. (See Process 10 for software data.)

> "We introduced the static MLC at an ASTRO (American Society for Radiation Oncology) trade show meeting. The response was like nothing we had seen before. People were standing 10-20 deep in our booth trying to see and learn about the new MLC. This device ushered in the era of 3-dimensional conformal therapy." –R.L.
>
> About Z.F., the university medical center physician who advocated aggressive use of the multileaf collimator in a quotation above: "He was a father figure to me while I ran things, and he taught me as much as anyone." – T.G.

Process 9 – Imaging upgrades. A. Co., a European manufacturer of radiation therapy equipment that sought to leave the business in the late 1980s, had superior imaging technology. The Medical division bought it and introduced a product for positioning patients based on the technology. Varian established its imaging laboratory at A. Co.'s radiation therapy headquarters. Later, Varian technologists in California and the European lab introduced amorphous silicon-based imaging and ability to view 3D images used in treatment planning (see Process 10) and images taken at the treatment machine together – enabling nearly perfect alignment of the patient for treatment.

> "What I did more than anybody else was relentlessly pushed on the engineering and marketing organizations to think about how it could be solved. They came up with design after design after design that was flawed. Until one day we picked up a piece from this idea, a piece from that, a piece from that, and put it together." – T.G.

Process 10 – Treatment planning. From early radiation therapy, small firms had sold systems to help doctors plan treatment. However, the complexity of modeling the inside a human body was so great that no system could be said to optimize – to identify ideal angles for shooting the beam. In the 1990s, however, J.F. on a sales trip discovered a Finnish company, D. Co., that had leveraged a Nordic government-business research program in computer assisted radiation therapy (Dahlin, 1985) to create real optimization. Varian first represented D.Co. products in Europe, then bought the firm and introduced treatment planning based on its technology worldwide. Eventually the software could not only provide plans but project a plan on the linear accelerator's imager (created by Process 9) and adjust the patient's position precisely, ensuring treatment went exactly where planning said it should.

> "D.Co. had created a machine that actually worked in 3D. You could tell it what you want, it will take your input, optimize further. It involved really hairy mathematics, working in multidimensional spaces." - J.F.

Process 11 – Ongoing lower-level consultations. Building on a system of user consultations that the sales group had carried out from the 1970s, Varian in the era of the RT-2000 committee built lower-level councils and funded research that included work with emerging Varian products. This helped ensure that products did for doctors what they wanted in actual practice.

A Comprehensive Technology System

It had been 17 years since RL's first efforts to articulate a new strategy and more than 25 years since JF found mention of a multileaf collimator in a paper from Japan. Though goals may be said to have been inchoate, especially before the 1992 adoption of a specific summary, from the mid 1980s significant activities appear to have been intentionally directed toward something like the effective system that eventually emerged. The challenges of getting the elements of a system to work and getting them to work together effectively had been largely overcome.

> "If you had shown this to someone even in the 1980s, they would have said, 'oh, this is science fiction. It can't be done.'" – university researcher who serves part-time as a Varian medical director, discussing 21st Century radiation therapy.

Discussion: Towards a Theory of Creation of Technologically Transformative Complex Product Systems

Examination of the creation of Varian's complex product system showed it was built over considerable time through intertwined processes. This section analyzes the processes as a group, then compares them to the fragmentary available knowledge available on two other technologically transformative complex product systems. It uses this data to derive a preliminary theory of how such systems can be created.

The creation of the Varian complex product system is an example of action driven by market orientation (Narver & Slater, 1990), and by individuals within the organization acting to create market orientation. The 1980s leadership transition, which gave marketing-oriented leaders power and brought about cross-functional approaches replacing an engineering orientation can be seen as a reorientation (Tushman & Romanelli, 1985). Subsequent progress represented patching (Siggelkow, 2002). Varian added elements to its core product.

None of the elements added, moreover, represented radical change in the core product. The linear accelerators Varian has sold since the 1960s are the product of highly sophisticated physics. However, of the eleven processes reported above, the only one that pursued dramatic change in the linear accelerator, Process 3, was a failure. The processes that contributed to Varian's success were digital innovations perhaps not radically different from those being implemented in other parts of the economy. However, not all organizations implementing such technologies achieved the same degree of performance improvement.

Therefore, it is important to consider what enabled the performance improvement to be achieved. Three propositions help explain why the Varian process resulted in impressive performance improvement.

The literature on market orientation, even on innovation or learning related driven by market orientation, generally deals with fairly rapidly implemented innovation to meet customers current needs. (Slater & Narver, 1995; Baker & Sinkula, 1999) J.F.'s rejection of what he called the "huge counterforce in business who would say our job is to find what the market wants and build it" indicate he had encountered and explicitly turned against this approach. Varian leaders' actions, including the creation of a committee involving customers in the late 80s to envision its products a dozen years in the future, indicate an orientation to the market over a much longer term. They specifically sought out customers with credible opinions about very long-term needs. Therefore:

> **Proposition 1:** Market orientation at the Medical division involved not so much to addressing what the customer was asking for but what could be expected to serve the customer years in the future.

Patching is presented in the literature as a strategic activity undertaken in response to specific outside stimuli. Repeatedly successful patching is associated with rapid reaction to "high velocity environments" (Brown & Eisenhardt, 1997). Varian seems to have had some elements normally associated with firms that change continually in response to high velocity environments (limited structure, time-paced innovation), but did not have the continual change in perspective that successful firms in high velocity environments are noted for. Instead, Varian patching was consistently informed by a larger goal. It may not always have been clear, but the statements "We are here to cure more cancer" and later "integrated, networked, conformal radiation therapy" guided development processes.

> **Proposition 2:** A long-term vision that changed only modestly played a role in driving particular innovations and the larger system forward over more than a decade.

A large literature deals with the creation and management of interfaces, particularly user interfaces for technology systems (for example, Shneiderman, 2010). Most of the literature is written from the interface designer's point of view, however. At the Medical division, creating appropriate interfaces was important to strategic management. A complex, expensive, largely routinized process evolved for ensuring good interfaces both to enable parts of Varian's offering to communicate with each other and for end users to utilize it with relative ease and dependability. Varian developed wide-ranging relationships with users who would try out emerging products for further interface improvement.

> **Proposition 3:** Varian developed and gave extensive management attention to complex routines for design and management of both interfaces among parts of its system and interfaces users would work with.

No element of Varian's technological change after the mid-1980s could be called radical. No individual product introduction represented radical change. At the same time, a continual flow of innovations was by no means incremental. Tushman & Romanellli (1985) say of incremental change: "Middle management interpolates structures and systems during convergent periods." Few of the changes between the mid-80s and the mid-2000s were driven by middle management, and few could be called "interpolations." A long series of significant technological changes added up to transformational technological progress; the changes accumulated into a technology transformation. It may be appropriate to refer to this process as "cumulative" change.

Other Data Sources on Creation of Transformative Complex Product Systems

As discussed above, there is reason to believe that the creation of technically transformative complex product systems can have real economic significance.

Therefore, it is important to consider to indicate how transformative complex product systems generally are created and to what extent the processes found at Varian are likely to be peculiar to that firm. Do we have reason to believe on the basis of available data that we have a real understanding of how transformative complex product systems are created?

Available information on the creation of other technologically transformative complex product systems is in popular, biographical, financial, and business case literature. To evaluate to what extent we may have a credible preliminary understanding of how such systems are created, we have consider whether this information can add to our knowledge.

Extensive non-scholarly literature exists on Walmart and Amazon. The structure of the literatures on the two firms differs considerably, but in each case there is reason to believe the literatures are worthy of consideration in analysis of how the the large systems under study emerge.

Literature on Walmart. In the Walmart case, the literature is uncommonly diverse. It includes at least four autobiographies, journalistic accounts (Huey, 1991), muck-raking attacks (Fishman, 2006; Lichtenstein, 2010; Ortega, 1998) laudatory works (Vedder & Cox, 2006), and business cases (Foley et al, 1994). At least some of this – certainly the autobiographies, for instance – is based on solid understanding of the firm. The works, moreover, tell a consistent story.

Walmart's system-building is portrayed as CEO-driven, unlike Varian's. Though it may be tempting to suspect this is overstated CEO cult-ism, the data really does suggest a far more CEO-driven process. Don Soderquist (2005) was "dataprocessing manager" at Ben Franklin Stores, a chain of which Sam Walton was a franchisee, when Walton visited in the 1960s to discuss the future of retail technology. Soderquist plausibly describes the vision Walton offered as having been far before his time.

Regarding how Walmart managed the evolution of its system, the non-scholarly literature provides reason to believe that key elements paralleled Varian's. All descriptions of Walton portray him as highly customer-oriented. Books critical of Walmart do not challenge this. On consistency of long-term vision, Walton's own autobiography (Walton & Huey, 1992), Soderquist's, and others provide persuasive descriptions of consistent pursuit of the long-term goal of a successful, information technology driven discount chain to serve small-town customers. On interface management the evidence is perhaps less clear, but descriptions of Walmart sending programmers to work in stores and the information systems' group's motto "Think like a merchant" provide some support (Lundberg, 2002).

Literature on Amazon. The literature on Amazon is less diverse. However, the chief executive authorized a BusinessWeek journalist to write a comprehensive study on the firm. The resulting work (Stone, 2013) shows evidence of extensive data gathering and a skeptical eye. (Bezos' wife posted a negative review of the book on Amazon (Bezos, 2013)). There are reasons for caution. Like many works by journalists, Stone sometimes states what a person was feeling during an event without indicating how he learned of the feeling. However, the obviously extensive research suggests the general outlines of the story are correct.

Like the data on Walmart, the data on Amazon shows evidence of a more CEO-driven process than Varian's. There is also however, evidence that each of the features outlined in the propositions above about Varian existed at Amazon. Its market orientation and interest in technologies of long-term value was apparent in its development from early days of technology to customize the online experience for each customer. The guidance of a big long-term goal appeared in a first letter to public shareholders, which throughout emphasized the long-term nature of its project. The importance of interface management was seen in the hiring of a substantial "editorial" group very early in the company's history.

A Preliminary Theory

The similarities of the processes at Walmart and Amazon to those at Varian permit the creation of a very **p**reliminary theory of how technologically transformative complex product systems are created. This is presented in Figure 2.

Insert Figure 2 about here

It begins with one or more market-oriented leaders focusing on the market's long-term needs. The pursuit of long-term needs results in a wheel of innovation where perception of market needs leads to technology development, which leads to extensive work on getting interfaces right. This leads to improved performance.

However, the motivation to achieve what the market needs in the long term results in further perceived needs, which begin another turn of the wheel.

Because of the orientation to long-term market needs, the consistent pursuit of a more-or-less stable goal, and the care involved in the careful interfacing, the wheel can turn effectively for a considerable period, and new kinds of technology performance, perhaps unimagined at the start of the process, can be achieved.

Conclusions

An examination of the process by which the Medical division of Varian Associates and its successor corporation created a transformative complex product system has shown that key elements were a market orientation focused on what could be expected to serve customers far in the future, and extensive attention to both interfaces among system elements and user interfaces. Review of non-scholarly literature on two other transformative complex product systems suggests that these elements could be standard parts of the process by which such systems can be created.

The theory created based on these observations is, of course, very preliminary. There is reason for some suspicion about the data reviewed on the two retail firms, and Varian's process could turn out not to be representative of how technologically transformative complex product systems emerge.

The study here suggests, however, that the emergence of technologically transformational complex product systems need not be viewed as mysterious and calls for further research. Not all organizations investing in digital technology are achieving the results of Varian Medical, Walmart, and Amazon. The results these organizations have achieved supports the idea that digital technology is capable of greatly improving the importance of many kinds of systems. There is need for scholars to identify more complex product systems that have had transformative effects and to examine how these systems have been brought into existence.

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Figure 1
Creation of a Transformational Complex Product System in Varian's Medical Business

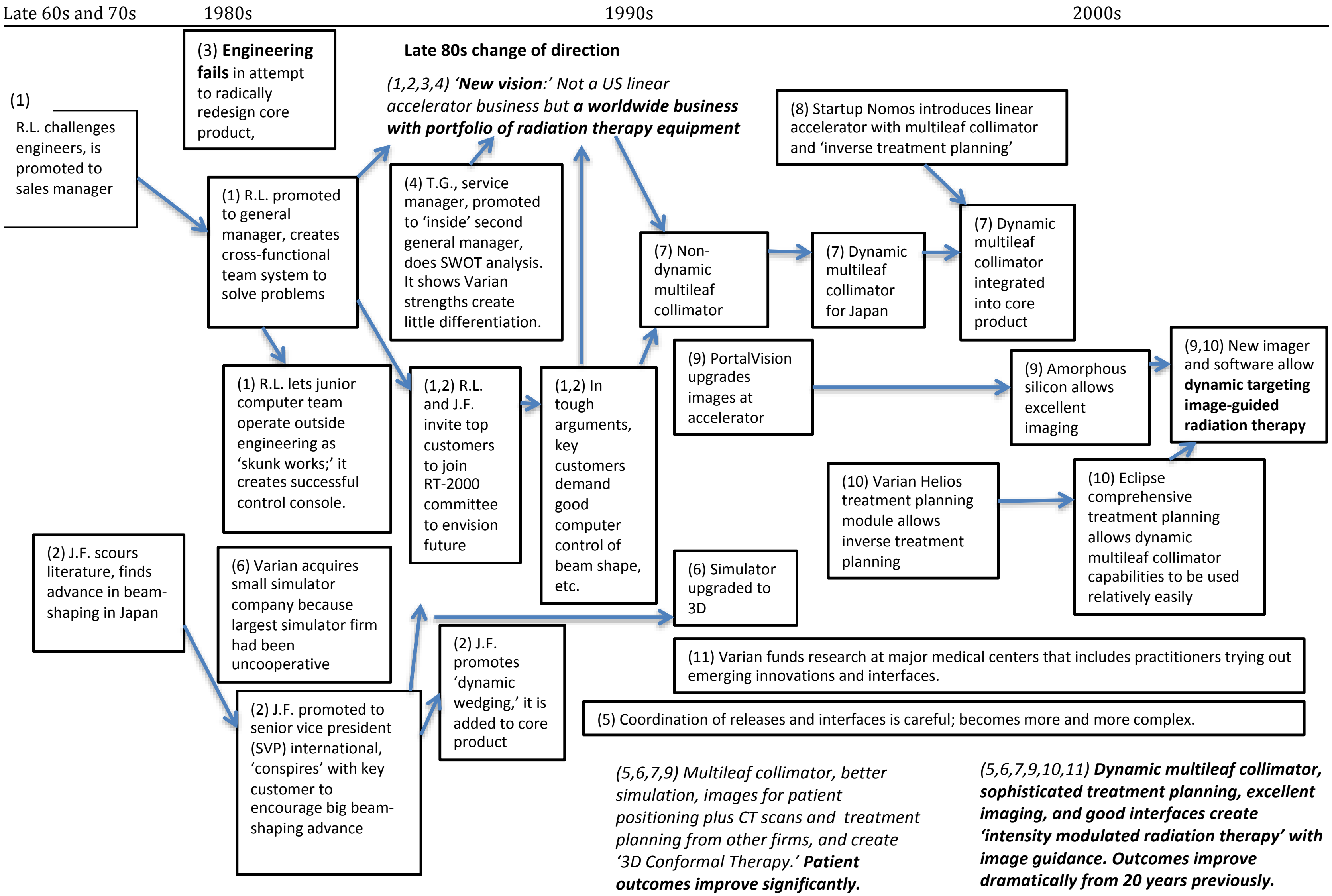

Figure 2
A Preliminary Theory of Cumulative Technological Change