Bringing Large Technology Systems to Economic Maturity

The role of technology management

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Abstract— **For long periods after their introductions, all big technologies have failed to create the kinds of productivity improvements that they would deliver in the long run. Many large technology systems today show the kinds of weaknesses found in the immature periods of earlier technologies such as those apparent in 18th Century steam-driven factories and early 20th Century factories where electric motors were added to steam-based systems. Users of today's systems often spend significant amounts of time struggling with functions and interfaces that work poorly. Yet today a few large systems do work with the kind of smooth reliability and comprehensiveness of function that supported economic takeoffs when comparable functionality was reached in the past. (The systems of Amazon.com and of some big box retailers seem to be examples.) This paper argues that such systems emerge through processes that are: 1) very long-term. They require multiple decades. 2) organization-wide. Rather than being dominated by a core technology group, they involve technical innovation throughout the organization driven by a chief executive's aspirations. 3) visionary customer-driven. The innovations were achieved by implementing a theory of what the customer would need well in the future.**

Keywords—innovation process; technological change; capability development

I. Introduction

As far back as the history of technology can be analyzed, big technologies have created serious frustration for the first generations to use them. Big new technologies have "bugs." They may provide amazing new benefits for people, but the most important improvements they can deliver will not be achieved without decades of work fixing the bugs, making complementary innovations, and re-structuring how society works [1] [2].

Steam is an example. The first British steam engine was patented in 1698. Steam does not seem to have contributed to higher wages till after 1830 [3].

Interchangeable-parts manufacturing is another example. The French general Jean-Baptiste de Gribeauval developed the idea of making things with interchangeable parts in the 1760s. Thomas Jefferson, U.S. minister to France a few years later, liked the idea and urged his compatriots to adopt it. And Americans worked hard to do so. Yet despite clocks, locks, and guns made with interchangeable parts in the first half of the 19th Century, it was at least 1870 before that effort could be said to be having an impact on growth as economists would measure it. It was 1910 before products made with interchangeable parts (including mass-produced autos) clearly had a transforming impact on daily life [4].

Yet anywhere in an urban or suburban environment today, chances are products made with interchangeable parts surround you. Many of the most successful businesses of the 20th Century, from Ford Motor to IKEA, were built on the working out of de Gribeauval's idea.

When economically mature, these technologies not only produced profitable businesses. They drove eras of business and economic growth and transformed human life for the better in today's developed countries. The technologies and the businesses that effectively developed and used them created a template for that emerging economies are struggling to adopt today.

II. The Question of Big Technology Systems

This history raises an important set of questions for businesspeople and those who study them today. It is now 70 years since the completion of ENIAC, the first large all-electronic computer. In many respects, computing-based inventions seem far more impressive than those of the early generations of other technologies. Yet the computer has yet to create the kind of widespread prosperity that previous technologies produced [5]. This paper asks: Why not?

Moreover, and more crucially for businesspeople and those who work with them, this paper discusses the few large computing-based systems that seem to work as well and fit into economic life as well as the technologies that drove previous economic takeoffs did during the takeoff eras. It examines current evidence on what it has taken to create these systems. Finally, it discusses how researchers might develop a deeper understanding about how organizations today can create systems useful in the kinds of ways that past technologies were during takeoffs.

Today, we do not have comprehensive explanations of how to create technology systems that will operate with the kind of crisp reliability that interchangeable parts manufacturing, for instance, was finally able to del illustration of the limits of our knowledge is the conflict between the points of view of the Harvard Business Review and the M.I.T. Sloan Management Review on creating effective technology systems.

Carr's claim in Harvard Business Review that "IT Doesn't Matter" [6] continues to challenge information technologists. Carr argued that information technologies were being transformed "from potentially strategic resources into commodity factors of production" (p. 42). He said new systems were unlikely to be major sources of competitive advantage. Carr argued that an important principle of IT management in the future would be, "Follow, don't lead." "Moore's law guarantees that the longer you wait to make an IT purchase, the more you'll get for your money. And waiting will decrease your risk of buying something technologically flawed or doomed to rapid obsolescence" (p.48).

On the other hand, the M.I.T. Sloan Management Review argues for the power of IT for positive transformation. In health care, for instance, it contends that a leading hospital's system has made care "safer, faster and cheaper" [7]. An editor argues that companies need to do strategic planning with a ten or twenty-year time horizon – a behavior he acknowledges is counter-intuitive given the unpredictability of technology. While publications like the Sloan Review provide substantial evidence of the power of the best systems, however, they do not really tell how such systems can be created [8].

An important challenge, then, is to analyze how high performing systems can be brought into existence.

III. Economically Mature Technology Systems

The literature that shows major technologies generally exist for long, difficult periods before they dramatically improve measured economic performance usually refers to them as "general purpose engines" or "general purpose technologies." Paul David popularized the concept in a 1990 paper that examined the history of electric motors. There, he described general purpose engines as "key functional components embodied in hardware that can be applied as elements or modular units of the engineering designs developed for a wide variety of specific operations" [1, p. 355].

David described how early 20th Century electric motors, though they worked well and were potentially far more flexible and efficient than water or steam power, were not widely adopted before the mid 1920s and did not necessarily produce large productivity improvements where they were adopted. Productivity had not risen much between the construction of the first electric generating stations in 1881 and the early 20s. However, David rapid factory productivity growth based on electric motors began in the 1920s and continued for decades thereafter.

Nineteenth Century factories had been built around water or steam power sources. Both types of power plant were much more efficient if they were large. Power shafts and belts transferred power to every machine in a shop from the main source.

Factories were built several stories tall so that the belts could bring more power to more equipment. Thus, moving raw materials and unfinished parts around was difficult by today's standards. Doing any significant re-arrangement required shutting everything off.

When engineers and factory owners brought much-more-flexible electric motors into these workshops, they could not alter the fundamental difficulties of getting things done there. Only when vast power networks reached large swaths of the United States, complementary innovations had been made, and owners could justify new factories to run exclusively on electricity did productivity rise. New factories in the 1920s were built without power belts and usually on one level. They represented a whole new system – a radically new one created with much difficulty. David's work spawned a considerable literature on how major technologies have followed the pattern he described [9]-[13].

However, Field noted that the technologies discussed in this literature did not all meet David's definition of a general purpose technology [14]. Even steam engines, treated as archetypal in much of the literature, were not during their era of greatest significance "functional components embodied in hardware that can be applied as elements or modular units."

Field said, however, that the main points David and others had made about the technologies they discussed were, in fact, accurate and seemed to be true about major technologies generally. The major technologies discussed in the literature did take considerable numbers of years before they could deliver their greatest economic benefit and they did need to work well and fit into people's lives well before they could do so.

To avoid confusion and to make the general argument that the literature on the history of technology supports, this paper simply refers to "major" or "big" new technologies.

Much of David's analysis has received a good deal of empirical support, however. The key conclusions for practice seem to be that that to have the kind of large productivity impacts they are capable of, big new technologies and the systems in which they are embodied must be mature in two ways:

- They must work very well.
- They require that extensive complementary innovations necessary for the technology to relate well to the economic lives of people in society be completed and fairly widely diffused.

Systems must effectively leverage innovational complementarities whose potential is not obvious to those who originally conceive of them.

An important possibility is that the reason computing is not yet driving an economic takeoff is that too few major technology systems today meet these criteria. Creating such systems can be a source of sustained competitive advantage for firms, probably for firms in a wide variety of niches.

IV. Limitations of Large Technology Systems Today

Today our technical abilities vastly exceed those of earlier eras, driven by Moore's Law and related discoveries [15]. We have reason to believe they will continue to advance far faster than they did in the 1960s or 70s. However, technical sophistication has never been an excellent predictor of business success or national prosperity [16].

Many systems such as those introduced into office work in the 1990s did increase productivity. (See, for instance, [17].) In many ways, however, our large systems continue to have a great deal in common with systems from the early days of steam, interchangeable parts, or electricity. In education, for example, Gordon noted computers have increased overhead costs without evidence of increasing productivity or performance [18]. In most of health care, gains have been elusive [19].

Even in offices – including at least some offices of sophisticated firms – people spend much time struggling to understand databases, to get one piece of software to talk to another, or to address computer security. Production in early 20th Century factories was slowed by the difficulties of making complete transitions from old power drivers to electricity and by the continuing complexities of running a factory set up to run on water or steam power. Productivity today is slowed by the continuing difficulties of shifting from paper to potentially flexible digital systems and by difficulties of creating truly efficient, flexible digital systems.

A. Examples of Mature Technology

Today the economy does, however, have a few large systems that clearly work very well and relate well to people's lives. It may be reasonable to consider them as models of ways our technology can contribute to a new prosperity and to examine the processes that created them for elements of processes that might be applied elsewhere.

At Amazon.com, for instance, despite incredible sophistication of its databases, the large number of software programs that Amazon makes work together, and the overwhelming security challenges of such an enormous operation, users rarely report the difficulties that many experience with technology in their own offices.

The parts of Amazon that sell books – with their well developed recommendation engine, deep connection with the sellers of used books, and remarkable logistics systems – are economically mature in the sense that the basic factory technology of mid- and late 20th Century factories was. They work very reliably and well, and they meet needs of people's daily lives without creating great amounts of frustration and confusion. If some other Amazon services don't yet work quite so well, they are moving toward that level of capability. (Amazon's processes are generally well documented in [20].)

A system from the 1990s that worked very well and produced descendants that work very well is that of Sam Walton's Walmart. Walmart in the Walton years created technology that smoothly managed products from factory to customer checkout, and then smoothly managed re-ordering. Based on a Harvard case published two years after Walton's death, Walmart's systems saved it an amount equal to 3.1% of sales just from reductions in the cost of in-bound logistics and regional offices – and these were by no means the only benefits from the systems [21]. Competitors learned from Walmart's efforts and the retail industry as a whole grew rapidly more efficient. Studies by both McKinsey & Co. [22] and the Federal Reserve Bank of Chicago [23] showed wholesale and retail trade generally and Walmart specifically accounted for an overwhelming share of the increased productivity growth that the U.S. economy experienced in the later part of the 1990s. The Chicago Fed, for instance, estimated that wholesale and retail trade accounted for three-quarters of the acceleration in total factor productivity growth in the U.S. in the later part of the 1990s.

B. IT Does Matter?

This evidence shows that Carr is not entirely correct. IT sometimes matters tremendously in a strategic way. Today Walton's heirs are Nos. 11, 12, and 13 on *Forbes* magazine's list of the richest people in America. Carr could dismiss this by noting that Walton did his work in the early days of computing, when computing was more of a rare and strategic resource than it is today. But Jeff Bezos of Amazon is No. 2 on the list. Amazon was a mid-sized firm in 2003 when Carr published, with its survival by no means assured. Stone [20] shows many managers were leaving Amazon at the time because of the frustrations of the company's struggle to succeed. Today, however, there is no greater strategic success.

The success of systems like Walton's Walmart's and Bezos' Amazon's provide evidence that other technology systems could, at least in principle, work a great deal better than they currently do and that creating such high functioning systems can result in remarkable profits and sustained competitive advantage. Thus an important challenge, 70 years after ENIAC, is to get other technology to work with the maturity of these systems – maturity comparable to the maturity that previous technologies eventually achieved. Mature versions of other systems would create vast benefits for customers and society as well as profits.

V. Principles for Successful Systems

Understanding how such systems emerge and the roles that leaders and others play in their emergence will not be simple. But at this early stage in analysis, it seems appropriate to posit three principles: 1) Creating economically mature systems is a very long-term process. 2) Creating mature systems calls for an unusual kind of "market orientation." 3) Creating mature systems requires building a community of managers throughout an organization dedicated to constant improvement and reinvention of systems.

*A. **Long-term Process***

The evidence from the few systems that work as well as the systems that drove economic takeoffs in the past is that developing such systems is a remarkably long-term process. Both Walmart and Amazon worked for more than 20 years before the unusual success of their technological approach was obvious and before it contributed to profitability.

Today discussions of technology emphasize how fast it moves. The message is that it everyone must change quickly to keep up with progress. But many large systems outside the retail sector do not work as well today as Walmart's systems worked at the time of Sam Walton's death in 1992. Walmart's systems, however, were the product of careful building that began in the mid-1960s.

Walton did not push rapid technological change. He was infamous within Walmart for refusing to approve seemingly important technology upgrades if he did not see their relevance to the customer and the front-line employee. In his autobiography, Walton said: "Everybody at Wal-Mart knows that I've fought all these technology expenditures as hard as I could. All these guys love to talk about how I never wanted any of this technology…. The truth is, I did want it, I knew we needed it, but … I always questioned everything…. It seems to me they try just a little harder and check into things a little bit closer if they think they might have a chance to prove me wrong" [24, p. 117].

Constructing systems that will eventually achieve excellent usability may involve slow, relatively unprofitable initial work. Neither Walmart nor Amazon had much profit to show from their computing investments in at least the initial decade. In Amazon's case, the era of modest profit and continual system building began in the 1990s and continues today.

B. A Special Kind of "Market Orientation."

One of the oldest and best-established principles in the business literature is "market orientation" [25] [26]. Based on considerable, widely replicated research, it says that businesses that focus on the demands of their markets – that is, on meeting customers wants and needs – tend to do better than those that focus on beating competitors or advancing technology. Bezos' Amazon and Walton's Walmart had market orientation. Amazon, for instance, says its vision is "to be Earth's most customer centric company."

However, standard discussions of "market orientation" in the business literature do not at all give a sense of the market-oriented elements that led to exceptional information systems in these firms. The literature on market orientation only rarely discusses. Probably information technology is more difficult to manage in a customer-focused way than other functions because the raw material of hardware and computer code have so little direct, obvious connection to humans.

Walmart and Amazon both succeeded not only in orienting their IT efforts to customers but in establishing the centrality of improvement processes with long-term payoffs – even payoffs to the customer that had no obvious relevance to the bottom line. For example, Amazon developed precise, remarkably reliable mathematical answers to the question of where in its system to store a few copies of a book so it could reach the customers who were most likely to order most quickly and cheaply [20].

Walmart required programmers to spend time working in its stores. The information systems group's motto, like that of everyone in the company, was "Think like a merchant" [27, p. 88]. Systems had to be re-made over and over to approach frictionlessness. Don Sonderquist, chief operating officer of Walmart ten years after Walton's death, recalls: "The simple act of getting our merchandise from the supplier's dock to the store shelf received numerous makeovers, and we made an art of stripping excess cost and waste of any kind" [28, p. xix].

C. Community of Managers Dedicated to Improvement

Both Walton's Walmart and Bezos' Amazon built a community of managers who saw the constant improvement and reinvention of systems as at the heart of their jobs. Walton recruited retail executives, especially top managers, who were passionate about technology. He put them in positions such as a supervisor of store openings, vice president of merchandising or CFO in an era when other retailers found this inconceivable. Before most others recognized the power of computers, he made his chief information officer a formal member of the top management team. (Walmart's successes made other retailers copy this policy, and today it is common for retailers to other retailers to seek passion about technology in executives whose jobs do not specifically involve managing technology. In fact, other firms are believed to have surpassed Walmart in technology effectiveness [29].)

Amazon was equally aggressive in building an entire management team that could together build systems. Bezos had the advantage of forming his original team in the 1990s, an era in which it seemed natural to think of an Internet company creating a future that would work really well. Of the companies founded in that era, Amazon was one of very few to focus on building a team and a set of systems for the very long term, however. It is perhaps the only one to have fulfilled the era's hype.

Bezos and all his senior managers involved themselves deeply in the nuts and bolts of technology re-design processes. For example, Bezos and other top leaders climbed around conveyor belts in a distribution center in a team process that eventually reinvented how warehouses handling small orders should operate. Pure software projects equally important than distribution center conveyor belts. Amazon remade its personalization engine over and over [20].

VI. Creating Mature Systems

The above principles and the data that supports them suggest that a good deal is, in fact, known about how to create mature, profoundly effective systems with today's technology. Businesspeople can start working on that very difficult task of creating sus systems immediately. Today, others are certainly pursuing that goal with approaches that resemble Walton's and Bezos'. For example, it is possible to see the three principles discussed above in Vance's biography of Tesla chief executive Elon Musk [30].

On the other hand, it is important to stress that our knowledge is limited about how to create large technology systems that work very well and fit well into people's lives. It is possible that others are creating such systems through completely different approaches.

We know much less about how powerful, economically mature technology systems come into existence than we should. To learn more, we need careful theory-building research, case-study methods executed with rigor [31] [32]. Historical data on how earlier big technologies came to maturity may also help us to understand. What can the history of steam engine engineers, interchangeable parts mechanics, or the early history of AT&T [33] teach us about how to bring a big technology system to maturity?

Better understanding the process by which technologies reach maturity can make a real contribution to addressing a wide variety of social as well as technical problems as well as understanding an important class of opportunities for companies to achieve sustained competitive advantage. When examining historical data, special attention should be paid to the process by which well-paying jobs emerged from the maturation of previous big technologies. (Past big technologies made enormous contributions to the growth or emergence of almost all today's well-paying job categories, from office work to college teaching.)

We do not know exactly how much can be accomplished through these processes. Some contemporary economists argue that the failure of computing technology to advance the developed countries' economies in recent years simply means that computing technology is not as important economically as the technologies created in the 19th and 20th Centuries [5].

However, the achievements of the few systems that really work as well as earlier technologies did at the time they began to drive dramatic economic growth suggests those who argue the limitations of today's technology are probably overstating their case. The evidence is that today's technology can do better than it is now doing, and that this can contribute to sustained advantage for companies and solution of many seemingly intractable difficulties for society. It calls for the pursuit of systems significantly superior to those that now exist in a wide variety of fields.

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