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TECHNOLOGY SUPPLY CHAINS: AN INTRODUCTORY ESSAY^{1,2}

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Although the topic of supply chain management has received a great deal of attention in the past few years, the vast majority of that attention has been focused on the logistics of supply chains: materials, transportation, and inventory management. Technology supply chains addresses a more fundamental set of issues: (1) assessing the present and (especially) future profitability and strategic leverage among the various sectors in the chain, (2) designing the supply chain (i.e., determining of the boundaries and identity of the organization) based on the strategic (as well as a logistical) assessment, and (3) assembling the capability to realize the organizational boundaries of choice and to manage within and across those boundaries.

This essay addresses strategic technology sourcing--the determination of what technologies are strategic to a firm (or nation) and the management of the policy options that follow from this determination. This work is certainly not the first word on this subject, nor will it be the last. In fact, we hope that it will stimulate significant discussion about strategic technology sourcing especially in those organizations where such discussion has been absent, naive, or just shouted down by the manage-by-the-numbers types. In the business press today, outsourcing is the rage. "Restructure and downsize your organization; outsource as many functions as possible" seems to be the message from many of the world's most profitable corporations--large and small--as well as their consultant-armies .

As has been demonstrated countless times, however, today's profitability is not necessarily a good predictor of tomorrow's. Today's customer or supplier-partner can quickly become tomorrow's competitor as turbulent markets and agile alliances respond attentively to every subtle shift in opportunity. How many of

¹Financial support for this project from within MIT--Leaders for Manufacturing, the International Motor Vehicle Program, the Industrial Performance Center, the International Center for Research on the Management of Technology, and the Japan Program--as well as from Chrysler, Intel, Sematech, and Texas Instruments, is gratefully acknowledged.

²We gratefully acknowledge the thoughtful contributions of a wide range of students, colleagues, and industry practitioners. A particular debt of gratitude is owed to the students in the MIT Technology Supply Chains research group who have worked on this project over several years: Betsy Adams, Ed Anderson, Nitin Joglekar, Maureen Lojo, Angela Longo, Sharon Novak, Charles Pieczulewski. In addition we gratefully acknowledge conversations on this subject with Dr. Daniel Whitney, Senior Research Scientist at CTPID, MIT who has an ongoing active intellectual engagement with this subject.

today's money-saving moves actually have babies being outsourced out with the bathwater?

Most firms (and nations) are not entirely self-sufficient technologically. Rather, they make strategic decisions as to what technologies are "core" to their business interests and then focus attention on how best to manage technology sourcing for core technologies. Even within a given industry, we often see dramatically different decision outcomes in this area. For example, Honda develops and manufactures a great deal of its powertrain and body assembly systems, whereas the "big three" U.S. car manufacturers outsource the vast majority of this type of technology, with Chrysler typically outsourcing the most. In microelectronics, IBM and Toshiba each maintain significantly more in-house semiconductor manufacturing technology infrastructure than does Intel, despite Intel's larger semiconductor revenues. Furthermore, technology sourcing decisions can affect significantly the fortunes of companies. Witness the results of IBM's circa-1980 decision to outsource the technology for their personal computer microprocessor and operating system, respectively, to Intel and Microsoft, which contributed to a decline at IBM and dramatic growth at those two technology suppliers. On the other hand, Chrysler's aggressive technology outsourcing often is asserted to be an important contributor to its low-overhead cost structure and high per-vehicle profits (but is also pointed to as a potential obstacle to direct control of quality improvement processes).

Our interest spans sourcing of both components and manufacturing technology for manufacturing firms. However, we believe that technology sourcing for manufacturing technology is more complex and better illustrates the challenges in technology sourcing, so we give relatively more emphasis on this domain. In particular, manufacturing equipment is a high-leverage industry (these are the "machines that make the world"). In addition, as product development best-practice methodology become more universally available, process development may increase in competitive importance. Furthermore, as labor content declines for products manufactured in the developed countries, equipment will increase as a percentage of total product costs, hence the need for capital productivity improvement. Finally, for some industries, the costs of switching equipment suppliers are higher than those for switching components suppliers. As a result, the *tension* over the value of loyalty and relationship-specific investments versus the value of maintaining freedom to shop is greater for equipment than for components.

The central messages of this topic are: (1) that technology sourcing decisions are of great strategic and economic importance, (2) that managing the technology supply chains (both internal and external to the organization) that result from these sourcing decisions is a critical management challenge, and (3) that much insight can be gleaned from a systematic analysis of corporate and national technology sourcing experiences, and that (4) one can be quite systematic about technology sourcing and develop promising strategies for sustainable competitive advantage.

MANUFACTURING MASTERY

Mastery of manufacturing is a central characteristic of the most prosperous and secure nations in the world. We argue that nations with mastery of manufacturing, especially mastery of manufacturing technology and equipment, enjoy a self-reinforcing, positive cycle of benefits that contribute to better jobs, higher living standards, more dynamic and innovative industry, and greater autonomy relative to other nations. We will call such this cycle a model of "success-to-the-successful."¹ Many of us have heard the same principle of positive reinforcement in the phrase, "the rich get richer." We argue that under certain conditions, nations that are best at manufacturing tend to remain the best, while enjoying the benefits of a healthy manufacturing sector. Yet as the title of this chapter implies in its intentional double meaning, mastery can be *manufactured*. History is replete with examples of the intentional creation of comparative advantage in manufacturing, and the successful pursuit of mastery in manufacturing technology. Yet many firms and nations, having achieved a certain level of mastery, have found that creeping complacency can lead to rapid reversals--the state-of-the-art mastery has a short half-life in many technologies. A central feature of this strategic competition for manufacturing mastery is the struggle for technological autonomy, and the diffusion of technology that undermines technological and productivity leadership.

This brings us to a central theme: the almost inevitable diffusion of manufacturing technology from its place of origin makes manufacturing technology a "wasting asset." Technology diffuses in part because people move across borders. In part, it is diffused because manufacturing systems are complex, and require the knowledge and skills of many individuals for their successful operation. Any one or several of these people may find a reason to take that knowledge elsewhere, either to employ it or to sell it.

Manufacturing technology leadership is not an asset or capability that can be protected or preserved indefinitely. This means that leadership in manufacturing technology is difficult to sustain. Productivity gains from a new technology reach the point of diminishing returns, and at the same time, manufacturers elsewhere purchase or purloin that technology, and begin to climb the productivity curve.

Captains of industry and political leaders would do well to mind the notion of manufacturing technology leadership as a wasting asset. Periods of manufacturing leadership are more like pit stops than victory laps: they are opportunities to develop increased wealth, skills, and resources in preparation for the next round of competition, rather than races completed and won.

¹ See, e.g., Peter Senge, *The Fifth Discipline*, 1991, for an explication of the success-to-the-successful archetype. Also see Paul Krugman, *Peddling Prosperity*, for an explanation of "the economics of QWERTY," which is essentially the same concept--of positive returns to scale.

CRITICAL TECHNOLOGIES AND AUTONOMY

Technology is a specific knowledge applied in solving a problem or performing a task. Technology can be embodied in a piece of hardware such as a silicon chip, or in the computer software and human intelligence used in design and development processes such as aircraft systems integration, or in an organizational technique such as flexibly specialized manufacturing.¹ In one view, technologies are critical insofar as they are *multipliers*, significantly enhancing the performance, cost, or quality of military or commercial systems.² That is, other things being equal,³ they provide decisive battlefield advantages or decisive marketplace advantages. An example of this notion would be productivity gains realized through the use of high speed robotic assembly equipment versus the use of human assembly of parts into end products.

Another view of the criticality of technology evaluates the *substitutability* of the technology in the production chain, and identifies the least replaceable as critical. The photolithographic steppers, for example, might constitute technology without which semiconductor manufacturing could not take place. There might be several such technologies associated with the manufacturing of any given product.

Still another view of criticality tries to estimate the *positive technological spillover effects* a particular industry will generate. For example, the network technology originally developed to hook together scientific researchers on the internet is now finding wide application in companies, from the manufacturing floor, to electronic connections between companies and their customers and suppliers. These three notions are complementary, and should be combined in any estimation of the criticality of a technology. Defense Department (DoD) analyses have focused on the force multiplier effect, and have neglected the substitutability effect, leading DoD to inflate its list of technologies and industries that it considers critical. An assessment of these three criteria for each candidate industry will reveal the U.S. *sensitivity* to disruption of supply.

Companies must consider the degree to which they will "go it alone" in technology development versus relying upon suppliers or partners for the technology necessary to design and build a company's products/services. These decisions impact all areas of the firm, including finance, product development, production, and distribution logistics. For example, should a firm choose to develop all of its production technology, as does Honda through its Honda Engineering division, the firm will incur a large fixed expense to maintain this capability. However, the firm will always have first access to the resource--which may be

¹ For flexible specialization, or lean production organization, see Michael Piore and Charles Sabel, The Second Industrial Divide, 1984; James Womack et al, The Machine that Changed the World, 1992.

² DoD used a factor of three as a guideline to significant performance improvement in the selection criteria for the 1990 Critical Technologies Plan.

³ "Other things" in the military case being approximately equal numbers on each side, competent leadership, and similar military technology (i.e., both sides have missiles and aircraft, etc.). In the commercial case, other things being equal includes roughly similar marketing capabilities, competent management, and similar, but not identical products and manufacturing processes. In such cases, the military or commercial outcome may hinge on the quality and performance of weapons or products that are either military "force multipliers," or commercial "sales," or "productivity multipliers."

crucial in markets where short cycle times for new products are a firm's lifeblood. Conversely, should a firm choose to outsource all of its production technology, as does Chrysler Corporation, then the firm will not incur fixed costs throughout its business cycle, but the firm may find itself competing with other manufacturers for the same resource during boom periods. Partnerships with suppliers are one way to mitigate this risk, but if a supplier partners with more than one company, and the those companies' peak demands coincide, the problem remains. Independence or dependence in some technology is neither good nor bad, per se. Rather, these issues must be considered in the context of a strategic supply chain analysis.

EXAMPLES OF TECHNOLOGY INDEPENDENCE

Honda Engineering

Honda provides an example of a company which has pursued a strategy of technology independence by producing the majority of the equipment used at the company's production facilities at its subsidiary tool making company, Honda Engineering. The U.S. operation of Honda demonstrates the systematic creation of the capability to create tooling in-house, in the same period when many other manufacturers were reducing their internal tool making capabilities, and relying more upon outside suppliers (see discussion of Chrysler below). In 1982, when Honda of America (HAM) began operations in the U.S., the tooling was imported from the Japanese division of Honda Engineering. In an effort to increase internal capability in the U.S., the Honda engineering division has grown from about 50 engineers in 1990 to about 200 in 1993. These employees, along with Honda R&D, were heavily involved in designing the manufacturing system for the Accord Wagon. The eventual goal is for subsidiaries such as Honda of America to do complete product and process design in local markets:

"However, it will take another 10-15 years before HAM is developing its own engines," says Lige Hundley, a Senior Coordinator at Honda R&D North America. "Honda is an engine company. To them, a car is a shell around an engine."¹

For Honda's investment in an internal tool division, they have purchased the ability to create machinery uniquely suited to their manufacturing environment:

Welding robots designed by Honda engineers typically occupy one-third to one-half the space of competitors'. ... Stamping dies, machining centers, injection-molding equipment, and robotics platforms offer examples of home-grown solutions.²

In a demonstration that they are not exempt from the laws of cyclicity, Honda has attempted to amortize some of the fixed costs of maintaining an in-house tool capability by offering its expertise to other companies, including competitors.³

Now, because of the cyclical nature of the demand for engineering, Honda engineers are available on a limited basis to help out other manufacturers. Last year 90% of Honda's

¹Schreffler, Roger, "A decade of progress; Honda's US operations," *Automotive Industries*, November, 1992, Vol. 172 ; No. 11 ; Pg. 46.

²Moskal, Brian S., "Want to Rent an Engineer?," *Industry Week*, March 7, 1994, Pg. 68.

³"Honda to Sell Proprietary Machine Tools," *Jiji Press Ticker Service*, Tokyo, December 9, 1992.

engineering services were devoted to Honda's internal purposes, and about 10% were devoted to other customers -- mainly the extended Honda family of companies or Honda suppliers.¹

For now, Honda has created a manufacturing system which has been able to produce excellent vehicles at competitive cost. The question for Honda going into the future is whether they will be able to afford the fixed cost of an internal machine tool division, and whether the internal division will be able to keep up with technological changes. The strategy of offering engineering services to other manufacturers may be seen as an attempt by Honda to ensure the long-term viability of its tooling capability. The strategy smooths demand and perhaps more importantly, exposes Honda engineers to other manufacturing systems, allowing them to learn of alternative manufacturing approaches.

General Motors - Global Purchasing

General Motors has maintained technology independence from its suppliers using a very different strategy than Honda. At GM, a large amount of technology is created through in-house divisions. For example, the company maintains ten die shops in the U.S. which support its many U.S. stamping plants. When technology is purchased from suppliers, bids go through several rounds of competitive bidding to a global supply community usually made up of a dozen companies. GM purchasing representatives claim significant savings in capital expenditures after adopting this system. (However, note the data presented below suggesting that the lost revenues to GM due to slow launches may swamp this number.) When asked if there were any kinds of technology which GM would consider not suitable for bidding out, GM purchasing representatives said no.²

Through this system of competitive bidding, there is no chance for GM to become overly dependent upon any one supplier. However, GM may miss out on the benefits of long-term relationships with its supply community. In addition, GM must maintain substantial in-house capability to be able to manage new suppliers on each project.

EXAMPLES OF TECHNOLOGY DEPENDENCE

Chrysler

Unlike Honda or GM, Chrysler has chosen to depend heavily upon a small number of suppliers for its body shop equipment needs. This has allowed the company to reduce its internal engineering staff substantially, leading to large fixed cost savings over the past decade. In exchange for substantial cost reduction (and very high short-term profits), the company has given up the ability to contribute as much engineering content to projects as does many of its competitors, and hence some ability to judge the technology they are being supplied. However, for this dependence, Chrysler has reduced its fixed expenses, and by using the same suppliers for successive generations of equipment projects, has tapped into an industry shared resource in body shop technology. There may in fact be advantages

¹Moskal, Brian S., "Want to Rent an Engineer?," *Industry Week*, March 7, 1994, Pg. 68.

²MIT Leaders for Manufacturing Equipment Purchasing conference, United Technologies Campus, Hartford, CT, January 19, 1994.

to Chrysler over a Honda or Toyota since technology may be more quickly adopted by a supplier doing business with several customers, than an internal or captive equipment supplier.

IBM - Microprocessors and System Software

Around 1980, IBM made a fateful decision in its personal computer (PC) business. Eager to enter the business quickly, IBM subcontracted two critical technologies, the operating system and the microprocessor, respectively, to suppliers Microsoft and Intel. In just ten years, IBM went from dominance in the industry to a company that has gone through dramatic downsizing. At one point in the last few years, the market value of Microsoft, a company with 1/10 the revenue of IBM, was higher than that of IBM.

TECHNOLOGICAL DEPENDENCE ISSUES AT THE NATIONAL LEVEL

Access to critical technologies for commercial purposes is a national security concern for two reasons: first, although some technologies are more useful for military applications than others, the line between military technology and commercial technology is a blurry one. In truth, all technology is "dual use," with commercial and military applications possible. And in the era of defense budget cutbacks, only commercial markets are large enough to sustain the economies of scale in production necessary to earn profits large enough to fund the next round of R&D. Thus, many "commercial" technologies increasingly surpass "military" technologies in performance and price. Second, many commercial industries depend on critical technologies in order to remain competitive. The vitality of commercial industry is central to the ability of a nation to build the wealth necessary to undertake political and economic tasks at home or abroad, such as space exploration programs, or economic and technical aid.

Concerns Arising From Foreign Concentration of Control

The notion of threat must be analytically separated from the notion of criticality. Threat is the stuff of politics and strategy, and involves an estimation of *vulnerability* -- the likelihood that one nation or firm will suffer from the influence (or attempted influence) of another in a particular issue area. Critical technologies become a matter for strategists to worry about when access to them is threatened. This threat arises when the industry producing the technology meets this criterion: the industry is concentrated such that there is significant foreign control, or the imminent potential for it. We define *foreign control* as location of production and/or research and development within the borders of a foreign country, or 51% ownership of an affiliate company by foreign investors from one country. This definition reflects the fact that foreign governments can use their power, legal and otherwise, to coopt or coerce companies or citizens for the purposes of achieving a national policy goal.

The most salient threat comes under the condition where one country (or firm) can significantly disrupt the global market. The level of foreign

concentration of control is the key element in determining the level of threat from foreign dependence. Many industries and many technologies may be claimed to be critical, but few are threatened by foreign concentration of control. Critical technology producing industries are not the concern of strategists simply on the basis of their criticality -- they are a concern based on an estimate of the national security threat from foreign concentration of control over the industry.

CONCLUSIONS

Supply chain design issues go far beyond the issues of logistics management. Economic, political, and organizational management issues all play a critical role. For policymakers in both firms and governments, a systematic framework and methodology are needed to guide decisions in this domain. The Technology Supply Chains Research Project at MIT is working with collaborators in industry and the public sector to develop a methodology that can serve this purpose.