nies in making these services available locally. If it created a viable system before other banks in the country did, it would still have something to sell.

Reading II–6 Management Criteria for Effective Innovation

George R. White

Early in the corporate era, it may have been easy to believe that technological stability was the normal condition and technological innovation the occasional, fortuitous balm for problems to which we otherwise could have adapted. But since World War II, innovation has been the norm; technology-based innovations, coming in rapid sequence, have been seen as the crucial source of prosperity, the panacea for all business problems.

Now we know that this panacea is not necessarily benign. The U.S. electronics industry was in far better condition in the early 1950s, before the emergence of the transistor, than it is now with the consumer business largely penetrated by Japan. On the other hand, it is also true that a previous modest participant in electronics, the Motorola Corporation, used the transistor to expand its position in consumer electronics and then, by integration backwards, gained a significant new role as a component supplier.

When compared to those available in finance, marketing, and production, the tools available to management for assessing and directing technological innovation are rudimentary. Intrigued by this fact, Margaret B. W. Graham and I determined to study in detail two fully completed, well-documented innovations—the transistor in consumer electronics and the jet engine in subsonic jet transports. We postulated that the criteria for success in these cases could be applied to predicting the future outcomes in two immature innovations—the supersonic transport and computerized automobiles.

Technology Review, February 1978, pp. 21–28. Reprinted with permission from *Technology Review*, MIT Alumni Association,

We conclude that we can in fact identify management criteria which effectively discriminate between profitable and unprofitable new technologies, and that these criteria have utility in appraising technological innovation in a wide variety of cases.

The Determinants of Success

We began by predicting that determinants of success could be found in both technology and business contexts. In the realm of technology, the determinants would surely depend on some appraisal of the quality and significance of the innovative concept itself: it must be new, and it must also be good. But such an innovative concept alone does not assure technical potency; there must be an embodiment for the new device, a product or system which is waiting for it. The embodiment surrounding an inventive concept has a major effect on how profitable the new technology proves to be.

Even with technical potency, a high rate of adoption and great profitability are not assured. The operational consequences of the new technology on manufacturing, marketing, and distribution must be considered.

Finally, market dynamics are extremely important—and often complex. Many industries have several dependent stages of intermediate demand; for example, transistor manufacturers sell to radio manufacturers, and radio manufacturers in turn sell to consumers. It is not enough to study the transistor market; analysis of final consumer demand is essential to understanding the outcome of transistor technology.

Balancing Old and New Constraints

Three questions turn out to be crucial in determining the technical potential of any inventive concept:

What fundamental technical constraints limiting the prior art are lifted? This is the key technical challenge: identify the core physical constraints underlying the previous technologies that have been lifted by the new invention, and assess the significance of lifting those constraints. Consider an example from the field of aircraft engines. In the piston engine, the upper limit in compression ratio is set by the detonation of the fuel charge in the cylinder. A turbine engine has no such limit; it is possible to have a higher compression ratio in a turbine engine than in a piston engine, and today's successful turbine engines do have those higher compression ratios.

What new technical constraints are inherent in the new art? The first question had to do with the credit side, and this question determines the debit side—that is, what fundamental constraints limit the effectiveness of the innovation. In jet engines, for example, the wake efficiency or the Froude efficiency of an aircraft propulsion system depends on the ratio of the velocity of the rearward stream of air to the forward velocity of the aircraft; the lower that ratio, the more efficient the propulsion. A propeller, moving a large amount of cold air slowly, has a higher wake efficiency than a jet engine moving a small amount of hot air rapidly, so a new constraint exists.

How favorable is relief of the former weighed against the stringencies of the latter? The net of the first two questions with respect to any inventive concept is a qualitative technical balance. The comparisons cannot be quantitative because they are not necessarily of similar characteristics; so this is highly judgmental balance, but it can be technically quite meaningful.

Putting Innovations in Context

The second stage of applying these management criteria is to analyze the embodiment in which the new technology will go to market. Here again the analysis takes the form of answering three questions:

Is the end product enhanced by additional technology and components required to make use of the innovation? This question calls for an analysis of the changes which must be made to a product if the innovation is to be used in it. A good example occurs in radios. Every radio must have a power supply, an R-F section, an I-F section, and an audio section. The transistor penetrated the automobile radio as a replacement for the output power tube, but the R-F and I-F sections of the radio were unaffected by the presence of a germanium power transistor instead of an output power pentode; however, because the output stage no longer required 300-volt B+ plate potential, it was possible to eliminate the unreliable vibrator power supplies as soon as R-F and I-F tubes requiring only 12-volt B+ potential were developed. These hybrid radios were much more reliable, but they could not have succeeded without the 12-volt tube development.

Is the inventive concept itself diluted or enhanced by the embodiment required? Now analyze the effect on the innovation itself of the changes required for its use in the product. There are favorable cases where the additional art surrounding the new invention enhances its value; that is a very happy situation. But there are many cases where the embodiment surrounding the new art dilutes it.

Does the additional embodiment offer opportunity for further inventive enhancement? Once more a balance is needed, this time between the value added to a product and that subtracted from it by the requirements of the innovation. Does it add more punch, or does the new innovation on balance decrease the acceptability of the product into which it is incorporated?

A Balance Sheet on Financing Business Operations

The answers to these two sets of questions establish the technical potency of a new innovation, but they offer no criteria in the business context from which to judge such things as profit potential. Three questions are also involved here:

What previously emplaced business operations are displaced or weakened by the new innovation? Assess the potential changes in existing business that will be brought about by the innovation. In the case of the entry of the transistor into electronics, the impact on the dealer service network is a perfect example. All tube sets were guaranteed to have tube failures and to require tube replacement. That phenomenon simply does not exist in transistor devices, and the dealer service network predictably declined in importance as transistors were introduced.

What new business operations are needed or wisely provided to support the new innovation? Assess the nature and cost of new business operations required by adoption of the new technology. The Japanese penetration of the U.S. consumer electronics market provides an example; it was simultaneously an innovation in distribution and retail marketing. Trading companies were now the distributors, and retail sales by stores, department stores, and discount houses replaced the previous pattern of selling which focused on the brand-franchise dealer.

How favorable is cessation of the former practices weighed against provision of the latter? Draw the trial balance again; we claim that this analysis can yield a qualitative business balance stemming from the new invention.

What Will Sell and What Won't

Finally, we determine a set of criteria having to do with market dynamics, on the basis of three questions:

Does the product incorporating the new technology provide enhanced effectiveness in the marketplace serving the final user? The Pilkington Float Glass Process represents a substantially more effective way of making plate glass by casting the glass against molten tin instead of grinding the surfaces; there are dramatic cost savings. But smooth glass is smooth glass, and there is no increased effectiveness resulting from its use in windows. The process is a perfect example of an innovation which made no change at all in the marketplace; it does not, unlike many others, yield economic payback because of market expansion due to enhanced effectiveness.

Does the operation reduce the cost of delivering the product or service? Taken together, this question and the one above are really the scissors of supply and demand, the first dealing with demand, the second with supply. If the answer to both of these questions is no, we can forget the whole thing; and if it is yes, then there need be little market uncertainty. The challenging case is where one of these is positive and the second is not.

Does latent demand expansion or price elasticity expansion determine the characteristics of the new markets? When the factor driving a market area is lower price per unit, market expansion by hundreds of percent is hard to obtain; major expansion in revenue is much more likely when the change in the market is driven by a dramatic change in product effectiveness. This final question, of course, determines the quantitative business balance.

In these criteria, we have avoided terms such as *return on investment* and *return on assets managed*. Our view is that these issues are overwhelmed whenever a new inventive concept can be placed in a beneficial embodiment which will enhance its value in a major latent market with lowered operational costs. If evaluations of an innovation must be based on assumptions of narrow differences in return on investment, they are quite possibly based on fallacy. What we propose is a logic structure to identify a small class of innovations of great promise whose success will transcend the cash value of any normal investment.

Putting the Determinants to the Test of History

Some examples from our work show how this logic structure might have served as a meaningful discriminant between successful and unsuccessful innovations in the past.

The Japanese Portable Radio Game

Consider first three aspects of the changes in the consumer electronics market wrought by the transistor. Transistor radios made their first strong showing in the U.S. portable radio market in 1956; prior to that time all portables had been tube sets. In 1956, the center of gravity of the U.S. market (according to listings in *Consumer Reports*) was in personal-size transistorized portable radios weighing an average of 20 ounces and costing an average of $57; eight models were available. This was a substantial innovation; the dominant radio in the previous year's market had been a tube-based portable weighing about six pounds. No Japanese sets were in the U.S. market in 1956.

By 1959, the U.S. industry had responded fully to the transistor as it was then applied; there were 25 portable models in the 20-ounce size, and prices were down slightly.

But in 1959, there was also a new market never populated before, filled by 11 different Japanese miniature portable sets weighing about 10 ounces (less than half as much as the smallest U.S. radios then available) and costing 10 percent less than the 20-ounce U.S. radios. The Japanese had made a dramatic innovation in the size and weight of personal portable radios and thus had opened up a new market not serviced by the U.S. industry.

The Japanese did not do this by innovating in transistors; they did it by other innovations through which they reduced the sizes of tuning capacitors, loudspeakers, battery supplies, and antennas. It was the transistor innovation supported by these additional innovations that allowed the Japanese to open up this exclusive new pocket-radio market and begin their successful penetration into U.S. consumer electronics. In fact, the U.S. industry's innovation based on the transistor was an incomplete innovation; it had not taken advantage of the embodiment surrounding the transistor as the Japanese had done.

By 1962, the market outcomes were clear. In 1955, the U.S. market for portables was 2 million sets, all tubes, and all made in the United States. By 1962, the Japanese had captured 58 percent of the market, and they had in fact captured 68 percent of the market growth made possible by the transistor.

Auto Radios and TV: Who Needs Transistors?

Compare this history with that of the second transistor innovation, which was in auto radios.

In 1955, the only auto radios were tube sets; they used high-voltage R-F, I-F, and output tubes, and of course they required vibrator power supplies.

In 1956 came a new type of auto radio with no vibrator power supply, no step-up transformer, and no high B+ potential. Germanium output transistors allowed low power drain; they were driven directly by the negative-ground 12-volt power supply of the automobile battery. In addition, an embodiment innovation provided 12-volt B+ tubes to handle R-F and I-F.

Only one year later, the first all-transistor auto radio, completely transistorized in R-F and I-F and with low-drain output transistors, all running directly on the battery supply, became available.

On average the tube sets of 1955 cost $45, the hybrid sets cost $8 more (a modest step-up), and the completely transistorized sets of 1957 cost $125, a luxury prestige item in the Cadillac Eldorado but otherwise priced out of the market.

The production of auto radios follows very closely the production of automobiles. In the mid-1950s, 67 percent of new cars went to market with radios. Since then this figure has increased steadily—no sudden changes in auto radio use have been associated with the new technologies—until now it is almost 100 percent. There were 6.86 million auto radios made in 1955 and only 6.43 million in 1960; these figures reflect almost exactly the volume of new-car demand. In this period, the transition from tube sets to the tube-plus-output-transistor hybrid set was essentially completed (fully transistorized radios were still not sold in any meaningful quantity). Yet there was no expansion at all in this market.

Turn now to color television consoles, the last of three transistor substitution innovations we have studied. All consoles marketed from 1955 through 1967 used tubes. The first transistorized console was available in 1968, but only in 1974 (almost two decades after the first transistor portable was sold) did transistorized color sets become the industry standard. Since portability and maintenance cost are dominated by the vacuum cathode-ray tube, transistor penetration was very slow.

Summing a Transistorized Balance

Portable radios, automobile radios, and color television consoles represent three different transistor innovations which were technically very similar in circuit design and in cost. Yet the business outcomes were dramatically different. Our criteria applied to this field reveal the differences in technology and its business context that led to these strikingly different outcomes.

Recall that our criteria reflected first a balancing of constraints removed against new constraints added by an innovation. In the case of portable radios, transistors meant that weight, size, and frequency of repair were all improved dramatically. For auto radios, the vibrator failure mode (which provided 60 to 80 percent of the maintenance engagement) was eliminated and with it the problem of battery drain when the radio was used without the engine running. Frequency of repair was generally reduced. In television, transistors served only to reduce the frequency of repair. As we progress from auto radios to television, the value of constraints lifted by the transistor declines.

New technology always has new problems. The audio fidelity of the little portable radios was poor, and that is a fundamental constraint. Similarly, the capture value of the tiny ferrite antennas was not as good as that of the bigger antennas. There were no particular penalties in auto radios or in television.

Drawing a technical balance on the value of these inventions, we conclude that the portable radios presented a vast increase in portability—from six to eight pounds down to shirt-pocket size. The auto radios offered a major increase in reliability. Transistorized television sets only had a slight increase in reliability going for them. We conclude that the portable radio had dramatic new value, the auto radio had substantial new value in its hybrid mode, and the television set had very little new value.

Next, what additional technology was required in the embodiments in which transistors were placed to realize their full potential? Small tuning capacitors, loudspeakers, antennas, and batteries were crucial to the reduced size of the portable radios. If these had not been included, the value of the transistor innovation would have been diluted, since in fact tubes were not the fundamental limit on the size of portable radios. As the Japanese demonstrated—to the detriment of their American competitors—only if you spent extra money to miniaturize all the other components could you fully capitalize on the transistor invention itself.

On auto radios, the additional innovation required for auto radios were the 12-volt tubes for R-F and I-F sections, and these were rapidly achieved. This allowed elimination of the vibrator; without that, the transistor innovation would have been diluted and transistorized auto radios might not have been successful.

An interesting situation prevails in television. As far as we can imagine now, a television set requires a cathode-type picture tube. Even after 20 years of looking, we find the prospects dim for a cheap, all-solid-state display. Therefore, we are nailed to the low reliability, high repair cost, and large size of present picture tubes. There is essentially no opportunity for incremental enhancement in the embodiment surrounding the transistors.

As we compare these different applications of the transistor on the basis of these criteria statements, we can understand why the portable radio transition was complete and rapid, why the auto radio transition was quite rapid for one portion (hybrid) and quite slow for the other portion (fully transistorized), and why the color television transition was quite slow. (See Exhibit 1.)

EXHIBIT 1

Effects of the Advent of the Transistor on:

	Portable Radios	Auto Radios	Television
Inventive concept			
Constraints lifted	Weight, size, and frequency of repair.	Vibrator failure, battery drain, and frequency of repair.	Frequency of repair.
New constraints	Low sensitivity, low fidelity.	None.	None.
Advantage	Vast increase in portability.	Major increase in reliability.	Slight increase in reliability.
Embodiment merit			
Additional components	Condenser, speaker, antenna, and battery.	12-volt R-F/I-F tubes.	Cathode-ray tube.
Dilution or enhancement	Dilution of size and weight gains.	Dilution if vibrator required.	Dilution, since no rewards of small size or low weight
Additional opportunity	Enhancement if above are miniaturized.	Enhancement if 12-volt tubes eliminate vibrator.	No enhancement; elimination of CRT seems impossible.
Operational practice			
Displaced business operations	Dealer service no longer very important.	Service less important.	Service slightly easier.
New business operations	Low transport and inventory cost encourage wide distribution network	New field of transistor and electronic manufacture opened.	None.
Advantage	Low-cost mass marketing opens new market to imports.	Radio makers integrate backward to transistors, auto makers to radios.	Slight if any.
Market dynamics			
Enhanced effectiveness to final user	Great increase only in portability.	Slight.	None.
Reduced cost	Higher cost in early years.	Only slightly higher cost, due to vibrator savings.	Much higher cost in early years.
Expansion of substitution market	Expansion in miniature size only.	Substitution.	Substitution.

Assessing the impact of the transistor on consumer electronics. The author proposes that analysis of these 12 aspects of the changes wrought by the transistor demonstrates why its penetration was so instant and its revolution so complete in the portable radio industry, its penetration equally complete but its revolution insignificant in auto radios, and its penetration small and slow in the television industry.

On the operational side, the transistor led to some business innovations. In Japan, a wholly new concept of low-cost mass marketing followed the design of nine-ounce radios.

The fundamental change in a key component of auto radios—the output tube became a germanium output transistor—was adopted throughout the industry and led to a new business opportunity. The Motorola Corporation, a radio manufacturer which never made tubes in its life, was effectively able to integrate backwards and started making germanium power output transistors—first for use in its own production of auto radios and also in its military equipment and later as components for sale to others. Thus this change in technology allowed Motorola to expand its role and penetration in the industry. The transistorized television set, having only slight advantages, offered no new business opportunities; essentially it is a null case.

The application of transistors to the portable radio definitely increased the effectiveness of the product to the final user; it now became a go-with-you-anywhere radio rather than a carry-it-and-set-it-down radio. The combination of the transistor and the further innovation surrounding it led to a new product that claimed a new latent market never populated before, rather than a substitution market. In contrast, the enhanced effectiveness of the transistorized auto radio to the final user was quite slight—a little bit of reliability, a little bit of battery drain. It was a substitution market; in fact, the total demand did not increase at all. There simply was one radio (approximately) for every new car sold. The television case is our null case; nothing happened.

The Battle of the Turbines

Here is a brief review of how our criteria illuminate the different outcomes in the case of turbine aircraft. Here we are dealing with three fundamentally different types of aircraft—the wide-bodied jets (707 and DC-8), the Lockheed Electra, and the Boeing 727. The first jets, as well as the first Electras, entered service in 1958. By 1961, the Big Five U.S. airlines (these firms provided 75 percent of U.S. passenger miles in the late 1950s, and they were historically the airlines which first bought new equipment) had 177 big jets; by 1969 they were using [illegible] such aircraft. The Lockheed Electra went from an initial 1961 fleet of 72 down to only 28 aircraft in 1969. The 727, which was not even in the first round of purchases, turned out to be the single most effective jet aircraft: by 1969, 400 of them were in service in the United States.

The inventions on which these aircraft were based were largely similar—the substitution of rotating compressors and high-temperature gas turbines for reciprocating pistons. But these aircraft are very different in their ensemble of other elements beyond turbine engines—embodiment merit, according to the terminology of this article. To achieve the full potential for higher speed inherent in the turbine, the 707 and DC-8 used swept wings, at 35° and 30°, respectively. This was possible because Boeing and Douglas engineers solved (each in slightly different fashion) the problem of controlling a phenomenon called Dutch roll, which affected stability. The outcome was that the 707 and DC-8 were fundamentally faster than the British Comet, which was designed with a 20° wing sweep to avoid the stability problem. Thus the opportunity came not in jet engines but in solving aerodynamic problems brought into relevance by jets.

Lockheed engineers were trapped with a dilemma in designing the Electra. They concluded that they were better off moving a large mass of cold air slowly than a small mass of hot air rapidly, because of the runway length requirements of the latter. So they stuck with propellers. But propellers in fact have an ultimate speed limit, since their tips cannot easily go faster than the speed of sound, and this in turn constrains the aircraft to a top speed nearly 200 miles slower than that of a turbojet such as the 707. The Electra designers chose the old, familiar art of propellers, where no risk was entailed but no new enhancement was possible.

The 727, the third member of our jet set, has been successful because of two additional embodiment innovations—fanjet engines and high-wing-lift devices. In order to use the short runways of intermediate-range airports, the 727 had to obtain much more take-off thrust and much more lift from the wing in landing than had been possible before; yet it also required a small wing for cruising at high speed. This was achieved by using fanjet engines (with cold air flow around the hot turbine exhaust) in the rear of the aircraft so that the wing was clean, and by using triple-slotted flaps with leading edge slats which provided the equivalent of a variable-configuration wing. The innovation was effective; the 727 ended up with short-field capability that matches that of propeller aircraft, yet it cruises at speeds typical of all jets.

Market dynamics are the next criterion of importance. The 707 and DC-8 presented a great advantage in comfort and speed; they flew higher and faster than any aircraft before, and it was simply more pleasant to travel. In addition, because of their high speed and capacity, they cost less per seat mile to operate than long-range piston planes. So the best of all possible worlds was obtained: demand was higher and cost was lower. These aircraft led to a strong market expansion for air travel.

The Electra offered only modest improvements. Some of the vibration coming from piston engines had disappeared, but Electras could not fly as high or as fast as the jets. Operating cost per seat mile excluding depreciation was less than that of medium-range piston aircraft, but this meant a market based on substitution (slowly penetrating by doing the same function against depreciated equipment), not one based on expansion (rapidly penetrating on the basis of payback from new customers).

Finally, the 727 had the speed and comfort of the big jets and costs roughly equal to the Electra, and it could fly in and out of the smaller airports. As soon as the 727 was available, all of the intermediate-range traffic, piston or Electra, went to it. (See Exhibit 2.)

Forecasting Future Innovation

Now that we have seen how the innovation criteria apply to the transistor case and to the case of jet aircraft, it is appropriate to make some general statements about their application to two prospective innovations, microprocessors for automobiles and supersonic transport aircraft.

Automotive Microprocessors: Everything Up

Microprocessors promise flexibility and precision of control and operation of automotive engines that are simply not available in mechanical control systems, and this is the heart of the technical advantage.

At the level of embodiment, we find that the sensors and actuators, not the computer chips, are the most crucial components requiring further development. An automobile is an analog mechanical environment; a microprocessor is a digital electronic environment. We need either sensors, actuators, and/or analog-to-digital converters, and these are the key embodiment elements. We also know that they represent the dominant portions of system cost and are the dominant determinants of system performance. If these can be made right, there will be

EXHIBIT 2

	707/DC-8	Electra	727
Embodiment merit			
Additional components	Swept wings required.	Propellers required.	High-lift wing devices needed.
Dilution or enhancement	Slight roll control problem.	Speed and maintenance constraint.	Clean wing with triple-slotted flaps from rear engine.
Additional opportunity	Speed advance over Comet due to high sweep angle.	None.	Short-field capability matches that of propeller aircraft.
Market dynamics			
Final user effectiveness	Great advance in speed and comfort.	Only modest gain over piston engine in speed and vibration.	Great advance in speed and comfort.
Cost reduction	Net cost less than long-range piston.	Cost much less than piston planes.	Costs roughly equal to Electra.
Expansion or substitution market	Strong expansion.	Substitution for piston craft.	Substitution for Electra and piston craft.

The battle of the turbine-powered transports. Only 6 of the author's 12 criteria are needed to demonstrate the superiority of pure jets in the marketplace—why the 707, DC-8, and 727-type aircraft became the standard for U.S. air travel in the 1970s. He believes the same kind of analysis can be used to show why innovations leading to a supersonic transport aircraft have much less potential in the U.S. market.

regulatory benefits, better driveability (which to the auto industry means desire to buy cars), and long-life, stable performance; automobiles will stay in tune and their control and performance functions will not deteriorate over the life of the car.

These will be major new design, manufacturing, and marketing opportunities, and our operational practice criteria are useful in seeing how to make a business operation out of these possibilities. Absolutely, one would expect that firms such as Bendix or TRW (with aerospace and electronic skills and a large presence in the auto industry) could take advantage of this opportunity to expand backwards (as Motorola did with auto radios) into special electronic precision sensors and actuators, seizing a key part of this technical ensemble for a long-term, stable market. We also have the possibility of car manufacturers expanding their domain of technical activities.

The market that is implied by these prospects for computerized automobiles is absolutely unique. It has been decreed by the U.S. government. Microprocessors and related control systems do not have to be evaluated against the cost of today's mechanical alternatives; they offer the most promising way we can yet envision to meet emission and economy standards mandated for motor vehicles in the 1980s. There is a billion-dollar value to manufacturers in avoiding the fines for high fuel consumption or the preemption of marketability if new automobiles fail to meet pollution standards set by federal law. The value to the auto industry hinges not on new revenue gain—because all the industry can hope to do is continue to sell high-value cars—but rather on the avoidance of loss.

The Fundamental Problem of the S.S.T.

To evaluate prospects for a supersonic transport, one can go through the same four-point check sequence on criteria. The key inventive concept, the thing that is fundamentally new on supersonic transports, is supersonic aerodynamics, the increase of aerodynamic drag at supersonic speed. Two different aerodynamic structures to deal with this problem have been examined in the United States. One (which is now a failed concept for transports) is the swing wing; the other, which survived until the entire transport project was shelved, is a wing swept back at an angle sharper than the Mach cone so the wing is subsonic while the airplane is supersonic.

This is a good concept. But it cannot deal with the fact that aircraft flying faster than the speed of sound always leave a sonic boom below, and the energy required to overcome that lost in the sonic boom results in high fuel consumption. So there is a good concept, but it has some debits.

Now we go to the embodiment criteria. The key regulatory decision was that sonic booms would not be allowed over the United States. So American supersonic aircraft must be efficient at subsonic cruise over the United States as well as at supersonic cruise over areas where boom is permitted. This requires what are called variable configuration engines, operating in bypass mode below the speed of sound and as straight jets above—a corollary innovation. The sharply swept wings present some unique control and stability problems; they lack the inherent stability of conventional wings, behaving much like classroom paper airplanes. There must be active controls, called "fly-by-wire." This is not hard, but creating reliable "fly-by-wire" equipment that will last for the 20-year life of an airplane presents a significant challenge.

A supersonic aircraft requires structures that go beyond those we have had before, because supersonic flight causes thermal as well as aerodynamic loads. The required composite materials represent a new art which now must be mastered.

Finally, we have a question about pollution: we absolutely know that oxides of nitrogen behave differently in the meteorological system at 65,000 feet than at 25,000 feet. The problem is that we do not know how they behave. If these oxides lead to depletion of the ozone layer, we will have somehow to change engine combustion.

If we understand all these embodiments surrounding the supersonic wing innovations, we can proceed to the issues of operational practice. The key problem here is that the U.S. domestic market has underwritten the basic costs of all major air transport innovations since the DC-3. It will not do so for the supersonic transport; long-range aircraft earn value only in international travel. Our airlines and our manufacturers need to understand what it means to be primarily international; pooling of traffic and manufacturing consortia are probable.

The market outcome is not clear. Is it an expansion market or a substitution market? We already have very effective long-range aircraft: if the only problem were to fly 4,000 to 5,000 miles, supersonic travel would be a substitution market, and the economics would not be optimistic. On the other hand, if the value of time saved is substantial, it is conceivable that supersonic travel could result in market expansion.

Having followed this procedure of drawing orderly balances in the areas of inventive concepts, embodiment merit, operational practices, and market outcomes, I have concluded that though no single constraint prohibits supersonic transports from being commercially successful, the broad array of concerns says that the mere passage of time will not assure an S.S.T. There must be some urgent national mission to override some of the constraints to their emergence.

We believe our procedure for evaluating the viability and likely outcomes of an innovation can largely account for the differentiated outcomes in high-technology businesses—businesses that are as far removed from each other as transistor radios and jet transports. When these criteria are applied to important potential future innovations, they indicate plausibility for a computerized car, given a reasonable regulatory atmosphere, and they indicate implausibility for many years for a U.S. supersonic transport. We are convinced that a similar analysis can be useful in indicating the likely future course of other projected innovations.

Reading II–7
Organizational Determinants of Technological Change: Toward a Sociology of Technological Evolution

Michael L. Tushman and Lori Rosenkopf

Abstract

This paper employs organization literature and concepts to help understand the path of technological progress. Our premise is that since technological progress is underdetermined by factors internal to the technology, it is the interaction of technical options with organization and interorganization dynamics that shapes the actual path of technological progress. Rather than reviewing technology as an autonomous force or as driven by an elite set of organizations, we argue that technologies evolve through the combination of random events, the direct action of organizations shaping industry standards, and the invisible hand of multiple competing organizations in a technological community. We suggest that the greater a product's technical uncertainty, the greater the intrusion of nontechnical factors in the product's evolution. Two fundamental factors shape technological uncertainty: the stage of the technology's evolutionary cycle and the technological complexity of the product itself. During periods of technological ferment, uncertainty is substantial. During these periods, organizational and interorganizational processes emerge to close on industry standards. Technological uncertainty is, however, minimized during periods of incremental technical change. We also suggest that technology can be described as systems ranging from nonassembled closed systems to complex, open systems. The more complex a product, the greater the number of subsystems, interfaces, dimensions of merit, and linking requirements. The more complex and/or open the product, the greater the technical uncertainty and the greater the intrusion of organizational dynamics in technological evolution. Technological cycles and complexity together affect the relative importance of organizational processes in shaping the path of technological change. As technology is an ever more important determinant of organization outcomes, the time is ripe to open up the black box of technological evolution; to use organization theory and research to understand the social, political, and organizational roots of technological change.

Research in Organizational Behavior 14, pp. 311–47.

Organization theory has long considered technology and technological change as influential determinants of organizational phenomena.[1] There is extensive literature on the effects of technology on organizations at the individual,[2] organization,[3]

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